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PAPERS ON

THE QUATERNARY IN NEW ENGLAND,

INCLUDING

4711

THE GLACIAL AND FLUVIAL PHENOMENA, OR THE DRIFT, AND TERRACES,

BY

JAMES D.wight DANA.

COLLECTED FROM THE AMERICAN JOURNAL OF SCIENCE, 1871 TO 1884,
AND THE MEMOIRS OF THE CONNECTICUT ACADEMY, 1870.

NEW HAVEN:
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1884.

PREFACE.

THIS volume is made up of the papers on the Quaternary published by the writer between the years 1870 and 1884, a few extra copies being on hand. The following is a list of my earlier publications on the subject, not contained in the volume:

Terraces in Oregon and California: Geology of the Wilkes U. S. Exploring Expedition, 4to, 1849, pp. 659–666, 670–674. Describes and figures terraces on the Willammet, Elk, Shasty, Sacramento and other rivers, from observations in the autumn of 1841, making them to be of fluvial and not of marine origin. Part of the facts are briefly given in the Am. J. Sci., II, vii, 247, 1849.

Fiords as evidence of former submergence: Geol. Expl. Exp., pp. 675–678; the fiords as evidence of submergence in the Glacial era, Am. J. Sci., II, xxii, 327, 1856.

Review of Chambers's Ancient Sea-Margins, with observations on the study of terraces, Am. J. Sci., II, vii, 1, viii, 86, 1849.

The Subdivisions of the Quaternary: ibid., xxii, 325, 1856, in a Paper on American Geological History. The subdivision of the era into the Glacial, Laurentian (afterward named Champlain, Manual of Geology, 1862) and Terrace epochs, is based primarily on the criterion of *change of level* over the higher continental latitudes, and *not* directly on the condition of ice or no ice; an upward movement separating the Champlain from the Terrace period, and a downward, that of the Glacial from the Champlain period; and, although the latter change cannot be regarded as demonstrated, I am still led by the observed facts to favor the view, that large areas over the higher latitudes were more elevated in the Glacial era than now; and that the Champlain period or period of submergence came in between the first great Glacial epoch and a second, and, therefore, that in Europe, at least, it was interglacial.

On a Mohawk valley glacier, Am. J. Sci., II, xxxv, 1863.

The following are the titles of the papers included in this volume. In some copies nos. 1 and 6 are absent.

1. Geology of the New Haven Region, Trans. Connecticut Acad., vol. ii, p. 45, 1870. Missing.
2. On the Quaternary, or Post-Tertiary, of the New Haven region, Am. J. Sci., III, i, 1, 125, 1871.
3. On the Connecticut River Valley glacier, and other examples of glacier movement along the valleys of New England, ibid., ii, 233, 1871.
4. On the position and height of the elevated plateau in which the Glacier of New England in the Glacial era had its origin, ibid., ii, 324, 1871.

5. On the Glacial and Champlain eras in New England, ibid., v, 198, 217, 1873. In this paper (p. 210) the author makes the suggestion that the coarse drift of Long Island was probable evidence of its origin as a terminal moraine, but not as that of its extreme southern limit (p. 207). The height of the Canada ice-plateau is here again considered, on p. 224 and beyond; and the point is also remarked upon, in vol. xxvi, p. 349, 1883.

6. On Southern New England during the melting of the Great Glacier, ibid., x, 168, 280, 353, 409, 497, 1875, and Appendix, ibid., xii, 125, 1876.

7. On the damming of streams by drift-ice during the melting of the Great Glacier, ibid., xi, 178, 1876.

8. On the Glacial phenomena of North America, by Professor Otto Torell, ibid., xiii, 76, 1877; followed by note on the Glacial era, by J. D. Dana, ibid., page 79.

9. Driftless interior of North America, xv, 250, 1878.

10. On the relation of the so-called "Kames" of the Connecticut River valley to the Terrace-formation, ibid., xxii, 451, 1881.

11. The flood of the Connecticut River valley from the melting of the Quaternary glacier, ibid., xxiii, 87, 179, 360, and xxiv, 98, 1882.

12. Note on the former southward discharge of Lake Winnipeg, ibid., xxiv, 428, 1882.

13. On the western discharge of the flooded Connecticut, or that through the Farmington valley to New Haven Bay, ibid., xxv, 440, 1883.

14. Phenomena of the Glacial and Champlain Periods about the mouth of the Connecticut valley in the New Haven region, ibid., xxvi, 341, 1883, and xxvii, 113, 1884.

A few notes, written as book-notices, are not included, which are here mentioned: On observations by Mr. R. Bell about Lake Winnipeg, etc.; on Belt's examination of the theories that have been proposed to account for the Climate of the Glacial period, and on Croll's view as to the submergence during the Glacial period, ibid., vol. ix, 310–318, 1875; on G. M. Dawson's Report on the Geology and Resources of the region in the vicinity of the Lake of the Woods to the Rocky Mountains, ibid., x, 384, 1875.

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. I, JAN., 1871.]

On the Quaternary, or Post-tertiary, of the New Haven Region; by JAMES D. DANA.*

I. THE GLACIAL ERA AN ERA OF GLACIERS, AND NOT OF ICEBERGS.

IT is still a mooted question in American Geology whether the events of the Glacial era were due to *glaciers* or *icebergs.* Agassiz and Guyot, who were long among the most active of Alpine explorers, found on their arrival in New England only the effects of glaciers. But American geologists are still divided in opinion, and some of the most eminent have pronounced in favor of icebergs.

The region of New Haven is exceedingly well situated for settling the question, not only as regards its immediate vicinity, but for the whole interior of New England. For in the first place, the region is a wide and open area at the southern termination of the Connecticut Valley;† and this valley is the great central valley of New England, including the larger part of its surface outside of Maine, the Green Mountains making its western border, and the White Mountains and the height of land southward, its eastern. Then secondly, the valley has a north-and-south course; so that, whether glaciers or icebergs were the agents, it would, in either case, have guided their great movements, and the New Haven region would have necessarily become filled with registers of the successive events. Being situated on an arm of the Sound, and at the same time extending inland for seven or eight miles along three streams that here have their discharge, the phenomena presented comprise results from both the sea and the rivers, and also from their combined action. On these several accounts, the New Haven region is eminently well situated for deciding the glacial question for all central New England.

A special study of the region during the last two years has led the writer to the conclusion that the effects are solely those of glaciers, or rather of a *Connecticut valley,* or *Central New*

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* The principal facts relating to the New Haven Quaternary, which I propose to bring out in the article here begun, are included in a paper by the author on the Geology of the New Haven region, published recently by the Connecticut Academy, in volume II, of their Memoirs.

† The Connecticut Valley has a general course from north to south, varying little from S. 9° W. It is occupied by the Triassic (or Triassico-Jurassic) Red sandstone formation from New Haven to northern Massachusetts, and this indicates the position which it had in the Mesozoic era. The Connecticut river leaves the valley at Middletown, taking there a southeasterly course among the metamorphic rocks of the eastern half of Connecticut.

England glacier.[*] To exhibit all the evidence bearing upon the question would require a full discussion of the whole range of facts presented by the New Haven Quaternary. I propose at this time to mention only a few of the more trenchant and decisive points.

The question is—Was the interior of New England in the Glacial era covered by a sea at least 4,000 feet deep for the floating of icebergs; or, was it emerged land as now, (perhaps to a higher level than at present) and submerged only beneath ice, the ice of an immense glacier, 3,000 feet and less in thickness, the ice in Vermont and New Hampshire being 4,000 feet and more above the level of the sea?

1. The sea, if it covered the land in the Glacial era, should have left proof of it along the southern coast of New England.

About New Haven, the height of the stratified Quaternary deposits above the sea (Long Island Sound), or above the river flats, nowhere exceeds 50 feet. This is the maximum; the particular facts will be stated at another time. Fifty feet is therefore the greatest amount of depression of the land which is indicated, the greatest that can be admitted by those who base their geological conclusions on facts. There are no traces of sea beaches or anything corresponding thereto at a higher level. On passing the level of 50 feet above the Sound there is an abrupt transition from the stratified to the unstratified drift, except along the courses of streams, and near these, there is the same transition on passing the level of 50 feet (or less) above the existing river flats.

The highest sea-level of the Quaternary era about the New Haven region is thus definitely marked. It is often assumed that the *unstratified* drift might have been dropped over the hills by icebergs; but, as Mr. Croll has recently urged, depositions in water cannot be made without stratification. The slightest jar of a vat of water holding sediment suspended will cause that sediment to go down in a laminated state; and so deposits of sands and gravels in the ever moving sea will always manifest their aqueous origin. The stratified and unstratified material about New Haven therefore mark the limit between aqueous and dry-land depositions. Much has been said about "modified drift" or more or less stratified drift deposits, over the hills; but they occur nowhere, according to my observation, except along water courses or about the sites of old lakes; they sustain the conclusion that the unstratified drift was essentially a dry land deposition.

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[*] The existence of essentially independent glaciers, (under the continental Glacier) in the Glacial era was recognized by the author in an article in this Journal, vol. xxxv, p. 243, 1863, and in his Manual of Geology, p. 763, published about the same time; and four great glaciers were there particularly mentioned, the Connecticut River, the Penobscot, the Hudson River, and the Mohawk River.

2. The magnitude, wide distribution, and regularity of direction in the scratches are evidences against icebergs.

This is no new argument; yet it has lost nothing of its force by long use. Broad furrows, eight to ten inches in depth, made in trap or granite over long distances, uniform in direction, must have required prolonged abrasion for scores of years, and by an abrading agent not liable to change of course through tides or currents, or to changes of form and thereby of center of gravity from waste in the waters over the rocks. Glacial abrasion has been found so generally wherever the soil has been freshly removed that it may be safely inferred, as has been done for other parts of New England, that the abrasion was universal. Passing from the New Haven region westward, over the high plateau of Litchfield, Warren, etc., 1000 to 1500 feet in height above the sea, the scratches have the same uniformity and wide distribution. Grounded icebergs would be sufficient for such results only in case thay spread completely over the wide surface and rested firmly upon its every part,—in which case they would be nothing less than partly submerged glaciers.

3. The scratches are, in some cases, in such positions that only a glacier could have produced them.

For example: on Mount Carmel—an east-and-west ridge in the Connecticut valley depression, about 750 feet in height, nine miles north of New Haven—along one of the steep southern valleys, the surface of trap (dolerite) is extensively abraded, and marked with many large and broad north-and-south furrows. An iceberg, moving southward, which could float over the top of Mount Carmel ridge would not touch bottom in this southern valley, for the part eroded is at least 150 feet below the level of the ridge to the north of it. While this erosion is, therefore, beyond the capacity of icebergs, it would be the natural result of a Connecticut valley glacier.

4. Since icebergs are fragments of glaciers broken off by the sea into which they descend, and since their freight of stones is part of the moraines of the old glacier, the boulders of the New Haven region, and of New England generally, should, on the Iceberg hypothesis, be the rocks of the White Mountains (whose highest peak, Mt. Washington (the loftiest in New England) is 6288 feet high), or of some Green Mountain Peak (over a thousand feet lower), if not from some more distant northern source.

But, in fact, the boulders about New Haven have come mainly from the central part of Connecticut and Massachusetts, and largely from the hills or ledges in the Connecticut valley itself; and not from any mountain summit or ridge either side. They are therefore from *the bottom* of the alleged Iceberg sea, and not from any emerged summits.

These boulders are masses of trap 1000 tons in weight and less; and Mt. Tom and Mt. Holyoke, situated adjoining the Connecticut river in Massachusetts, seventy miles north of New Haven, are the most northerly points from which such masses could have come. The tops of these so-called mountains would have been over 2600 feet below the surface if the Iceberg sea were 4000 feet deep. Other boulders are of the Triassic red sandstone; and these also had their origin *in the Connecticut valley*, south of the northern limits of Massachusetts, for none exists farther north. Others, of large size, some of them ten to fourteen feet in length, are of gneiss and came from a gneiss region, either in northern Connecticut, ten to twenty miles west of the Connecticut river, or just north of this in the adjoining part of Massachusetts. Again, six to eight miles west of New Haven, there are numerous large boulders of porphyritic gneiss, which were derived from ledges less than thirty miles distant to the north or northwest.

The facts show, beyond question, that in the Glacial era, the transported blocks came from the comparatively low regions, in the very bottom of the supposed Iceberg sea, not far to the north of New Haven, instead of from distant and elevated heights to the northeast or northwest; and this was true of all the drift material. The observations of others over New England, as well as those I have made over Connecticut, sustain the conclusion that the sand and gravel of the unstratified drift has not come from remote points, but has been shoved southward by some agent that could gather it up over the breadth of the land and bear it onward to drop it after a few miles, or scores of miles, of transportation. All this is evidently impossible work for icebergs.

Since, then, icebergs cannot pick up masses tons in weight from the bottom of a sea, or give a general movement southward to the loose material of the surface; neither can produce the abrasion observed over the rocks under its various conditions; and inasmuch as all direct evidence of the submergence of the land required for an iceberg sea over New England fails, the conclusion appears inevitable that icebergs had nothing to do with the drift of the New Haven region, in the Connecticut valley; and, therefore, that the Glacial era in central New England was a *Glacier* era.

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. I, p. 125, FEB., 1871.]

Note to Article I, of this volume, on the Quaternary of the New Haven Region; by J. D. DANA.

As my statement in regard to the essential independence of the Connecticut valley glacier, and others, in the Glacial era may be misunderstood, I would draw attention to the meaning of the words "under the Continental glacier" in the note to page 2,—in which it is implied that such glaciers are but the inferior portions of the great Continental glacier. I hold that, while the very large valleys of the land, like those of the Connecticut and Hudson, had great influence in determining the direction of the movement in these valleys, especially that along the axis of each, the whole movement must have been more or less modified by the movement of the great northern ice-mass; and that the counteracting influence of a valley depended not only on its depth and extent, but also on its direction and slope. The smaller transverse valleys caused no modification of the general glacier movement; but large transverse valleys gave to the ice in the middle of the channel their own course almost unmodified: if not when the great ice-mass had its maximum thickness, at least afterward when it had become thinner and had lost some of its motion.

I may allude to one other example, as I believe it is, of a partly independent glacier—that of the St. Lawrence valley; for the scratches on its rocks correspond mainly with its course, the prevailing direction, according to Dr. Dawson, being northeast. It should be said that these scratches are attributed by Dr. Dawson to *icebergs* in the Glacial era, which are supposed to have moved southwestward up the valley, the land being profoundly submerged for the purpose, so as to allow of a discharge of the ocean over the continent in that direction; and the fact that bowlders were transported *up* the valley is given as evidence in favor of this view. But, as in the case of the Connecticut valley, icebergs could not have gathered up stones in the bottom of the valley for transportation; and, further, as the era following the Glacial—the Champlain era—was an era without question of submergence to a depth of at least 500 feet along the St. Lawrence valley, there should have been icebergs succeeding to the great St. Lawrence glacier and made from it before its final melting; and such icebergs may well have been driven up the river, then a broad arm of the sea, and thus have distributed southwestward the stones which had been gathered below by the glacier in the Glacial era, besides accomplishing all else that can rightly be attributed to icebergs.

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ART. XXXII.—*On the Connecticut River valley Glacier, and other examples of Glacier movement along the valleys of New England;* by JAMES D. DANA.

IN former papers* I have spoken of the existence of a Connecticut valley glacier in the Glacial era; understanding by the expression, as I have said, that the under part of the great continental glacier lying in the Connecticut valley-depression moved *in the direction of the valley*—either while the great glacier was at its maximum thickness and held on its southeasterly course, or after its partial decline.

I propose now to give more fully the evidence with regard to the Connecticut valley movement; and, further, to show that other large valleys of central and western New England had also, in the same sense, their valley-glaciers—that is, they determined the direction of the ice that lay within them.

The facts appealed to in support of the conclusions are partly of my own observation; but they are mostly drawn, for Massachusetts, from the Report on the Geology of the State by Dr. E. Hitchcock, who labored with much enthusiasm in this department of the science; for New Hampshire, from an unpublished map by Prof. C. H. Hitchcock, kindly furnished me by its author; for Vermont, from the Vermont Geological Report, which contains the numerous observations of Prof. C. B. Adams, Prof. C. H. Hitchcock, A. D. Hager and Zadock Thompson; for eastern New York, between New England and the Hudson river, from the volume of the New York Geological

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* Manual of Geology, 1863, p. 544; This Journal, II, xxxv, 249, 1863; Trans. Connecticut Acad., ii, 45; This Journ., III, i, 1, and 125.

Reports by Wm. W. Mather, an assiduous laborer in this field of research.

We learn, first, from the scratches on the rocks *outside* of the larger valleys of New England—that is, over its higher lands—that the general course of the continental glacier covering New England was between S. 20° E. and S. 50° E. The true course, deduced from the magnetic, is here given, and so throughout the following pages.

On the high region of western Connecticut (1000 to 1200 feet above the sea), about Warren and Litchfield, the author found the courses of the scratches S. 29° E.; more to the west, east of Kent, on Kent mountain, S. 19° E.; to the south of Kent, about Newtown, S. 38° E. Percival observes that over this western part of Connecticut the direction of the transfer of drift was to the S.S.E. (probably meaning S. 20°–25° E.); and he cites as proof the distribution of blocks of limestone over Litchfield county from Canaan, and also of other rocks over the same and other counties. Mather gives for the direction in Litchfield county, Conn., near Norfolk, S. 20°–25° E., and Hitchcock, for that on Mt. Tom, the highest elevation near Litchfield, S. 17°–22° E.

West of the State of Connecticut, between it and the Hudson river in Dutchess county, not far west of Arthursville, I obtained for the course of scratches (which were common over the region) S. 24° E. Mather found in Putnam county (south of Dutchess), near Patterson, S. 17° E. to S. 22° E.; in Dutchess county, mostly between S. 15° E. and S. 30° E., but in some places S. 35° E.; and north of Dutchess county, in Columbia county (west of Massachusetts), mostly S. 18° E. to S. 30° E., with some on the mountain top east of Shaker Village and elsewhere in that vicinity, S. 45° E.

In the Taconic range, along the western boundary of Massachusetts, Dr. Hitchcock found the course of the scratches on the top of Mt. Everett (2600 feet above the sea) and on the adjoining Mt. Washington S. 18° E.; 15 miles farther north, on top of Tom Ball in Alford, 30 miles north of Mt. Washington, S. 43° E.; on the east slope of the Taconic ridge near Pittsfield (in same latitude nearly with the Shaker village above alluded to) and at Egremont, on the west slope, about S. 50° E.; a little south of the latter, on Lenox mountain, near the road from Richmond to Lenox, S. 38° E. Scratches observed by the [illegible]ter on Mt. Everett trended S. 27° E.

Again Dr. H. obtained for the course in middle Granvill[illegible] miles west of the Connecticut, S. 38° E.; between Otis [illegible] Becket, 30 miles west of the Connecticut, and farther north in Windsor, about S.E. For eastern Massachusetts (that is, the part of the State east of the Connecticut), Dr. Hitchcock gives as the average direction S. 24° E. He obtained in Royalston, nearly 20 miles west of the Connecticut, S. 18° E. to S. 38° E.

On the higher land of Vermont, away mostly from river valleys, the course of the scratches, according to the Vermont Geological Report, is for the most part between S. 35° E. and S. 55° E. In southern Vermont, on the higher land of Windham, 15 miles west of the Connecticut, S. 40° E.; in Wilmington, S. 29° E and S. 39° E. (intersecting): in central Vermont, in West Hancock, S. 50° E.; in Ripton, S. 60° E. In the northern half of the State, on Camel's Hump, 4088 feet above the sea, S. 55° E.; on Mt. Mansfield, 4430 feet high, S. 55° E.; on Jay's Peak, north of the latter, S. 50° E.; in Stowe, in the valley east of Mt. Mansfield, S. 35° E. Judging from the map in the Vermont Geological Report, which gives some observations not registered in the text, the average course on the higher lands away from the valleys is about S. 50° E.; and the same is not far from the course for the higher lands of New Hampshire, according to Prof. C. H. Hitchcock's map.

The facts show plainly that on the higher lands, both east and west of the Connecticut, and even over the elevated ridges of the Green Mountain range through Vermont, Massachusetts and Connecticut, and also west of this range over the eastern borders of New York, the great continental glacier had a southeastward course; in the latitude of Connecticut, about S. 25° E., and to the northward, S. 35° E. to S. 55° E. With such a course the glacier moved over the elevated lands on the west of the Connecticut river and the elevated lands to the east of that river, keeping onward, with little variation in its main movement notwithstanding the ridges in its course, and following no doubt the general slope of the surface of New England.

But this being true of the movement of its main mass, other facts show that the bottom ice of the great glacier followed often the courses of the valleys beneath it.

1. First as to the *Connecticut river valley ice.* This valley, or great north and south depression of New England, has its termination, as I have elsewhere observed, at New Haven, the Connecticut river channel leaving the valley at Middletown, Conn., and taking thence a southeastward course to the Sound. In the following table, the courses of glacial scratches along the valley are given for comparison with the course of the valley. It commences with localities at the south.

1. CONNECTICUT.	Courses.	Observers.
[illegible]f New Haven bay,	S. 10°–16° W. many	J. D. D.
[illegible]h of Meriden,	S.	J. D. D.
New Britain,	S. 15° W.	Percival.
Mt. Carmel, 7 m. N. of N. H.	S. 30° W.	W. B. Dwight.
Wadsworth's mountain,	Southwesterly	Mather.
2. MASSACHUSETTS.		
Granby, 7 m. E. of Conn. R.	South nearly	E. Hitchcock.
Mt. Tom,	South "	"
Mt. Holyoke,	South, S. a few degrees W.	"

MASSACHUSETTS.	Courses.	Observers.
Sunderland, E. side of Conn. R.	South nearly	E. Hitchcock.
Deerfield, S.E. part,	South "	"
Montague, E. side of Conn. R.	South "	"
Greenfield, W. " "	South "	"
Northfield, E. " "	South "	"
3. VERMONT.		
Vernon, for 2 m. W. side of Conn. R.	S.	C. H. Hitchc'k
Guilford, 5 m. W. of Conn. R.	S. 8° E.–S. 13° E.	C. B. Adams.
Brattleboro, for a great distance along C.R.	S. and S. 8° E.	C. B. A.
Dummerston, near Conn. R.	S.	C. H. H.
Putney,	S. 5°–12° W.	C. B. A.
Rockingham,	S. to S. 2° W.	C. H. H.
Norwich, 2 m. W. of village,	S.	C. H. H.
Norwich,	S. 15° E. and S. 39° E.	
Thetford, W. part of town,	S. 9° E.	C. H. H.
East Fairlee,	S. 6° E.	C. H. H.
Bradford,	S. 19°–30° E.	C. H. H.
"	S. 30° E.	C. B. A.
Newbury,	S. 12°–30° E.	C. B. A.
Waterford and Barnet,	S. 5° E. many; also S. 8° E.	

In New Hampshire, the courses of scratches, as represented on the map of the State by C. H. Hitchcock, referred to above, correspond very nearly with those of Vermont. According to it, scratches trending *west* of south occur in the river towns Chesterfield, Walpole, Hanover, Oxford, Haverhill, and still farther north, along the Passumpsic, in Monroe and towns adjoining it on the east.

Now the average course of the whole Connecticut river valley and of the Passumpsic valley, its true continuation northward, is about S. 9° W. But its different parts vary from this; that north of Massachusetts trending about S. 12° W.; that in Massachusetts, S. 6° W., but varying in the southern part to S. nearly; that in Connecticut from the Massachusetts line to Hartford, S. 3° W.; that from Hartford to New Haven, S. 18° W.; and the whole average for Connecticut, S. 15° W.

The table shows that the courses along the valley from New Haven to White River Junction or Norwich, Vt., are between S. 16° W. and S. 9° E., instead of between S. 30° E. and S. 50° E., like the scratches over the higher lands; and that, therefore, the average difference between the general course of the glacier and its course along the Connecticut valley is over 30°, that is, in the valley there are upward of thirty degrees more of westing.

In Connecticut, in which the average course of the valley is S. 15° W., the common course of the scratches is S. 15°–16° W.

In Massachusetts, in which the valley trends S. to S. 6° W., the scratches trend a few degrees west of south on Mts. Holyoke and Tom, or in part at least, as stated by Hitchcock; and as these are much the highest points in this part of the valley (their tops 1126 and 1211 feet above the sea level), they afford consequently the best evidence of the average direction of the movement in that region.

In Vermont, where the course of the valley for the more southern half is S. 12° W., the scratches trend S. to S. 13° E. But north of White River Junction the course of the scratches varies between S. and S. 30° E., yet many scratches at the farthest point, near the mouth of the Passumpsic, are S. 5° E. to S. 8° E.

In the part of the Connecticut valley south of Vermont the scratches conform closely in direction to the trend of the valley, and are the only scratches; while to the north there is a general southerly course in the scratches of the Connecticut river valley, yet at the same time about 15° less of westing than in the average trend of this part of the river. Moreover, in this upper part of the valley there are often, besides the valley set of scratches, another set having the southeasterly course of the great glacier.

The width of the region bearing the north-and-south scratches of the valley is generally twenty to thirty miles, but sometimes more. Going east or west of this there is a change more or less gradual to the course of the great glacier, and often also other scratches conforming to its course occur. In Massachusetts, in Heath, 15 miles west of the Connecticut, the course of the scratches given by Hitchcock is south with some westing, and the same on Mt. Pocomptuck in this town, 1888 feet high; and in Rowe, 20 miles west of the river, the course is S. 2° W. In southern Vermont, in Halifax, west of Vernon, and 10 miles west of the Connecticut, the directions given by Hitchcock are mostly S. 12° W.; but also, in *West* Halifax, 15 miles from the Connecticut river, S. 53° E.; in Marlboro, north of Halifax, S. 20° E. on high land; and also, at another locality, two courses, S. 7° W. and S. 53° E., intersecting.

The facts show beyond question that *the abrading agent of the Connecticut valley moved mainly in the direction of the valley.* The less degree of conformity of direction between the scratches and the valley in its *upper* portion is what should be expected; and so also the intersecting southeasterly scratches of this portion, and also of the region on either side of it a little distant from the river.

2. *Upper Champlain Valley.* The main part of Lake Champlain is the region of a vast plain—though a plain of water—and little or no conformity to its direction in the course of the scratches on its borders could be expected. At Burlington the courses are S. 19° E. to S. 31° E.; in Shelburne, south of Burlington, S. 17° E. to S. 29° E.; which courses show apparently that some diverting effect was produced by the main ridge of the Green Mountains. But the southern prolongation of the lake from Addison, and even from Ferris, southward to White-

hall, a distance of 40 to 50 miles, is very narrow, and occupies a proper valley, and here the scratches are parallel mostly to the trend of the lake—which trend is nearly north and south, excepting for the southern part, where it is about 16° *west* of south (S. 16° W.). Along this more southern portion, in Benson, the course of the scratches, according to the Vermont Report, is S. 8° E., S. 12° W., S. 15° W.; and in Orwell, just north, S. 8° E., S. 12° W. Farther north, in Bridport, the course is S. 20° W.; in Addison, S. 17° W. and S. 13° E.; at Larrabee's Point, S. 4°–12° E.; at Crown Point in New York, opposite to Bridport, S. 2° E. on the west side, and S. 27° E. on the east. In Putnam, N. Y., west of Benson, according to Mather, S. 10°–15° W. The conformity of the course of the scratches to the trend of the valley in its southern half is very close; in its more northern part, where, opposite Addison and beyond, the lake is over two miles wide, scratches both of the valley course and of the general course of the glacier occur together. The divergence in all, from the S. 40°–55° E. of the higher lands of the State, is very wide.

3. *Lamoille River Valley and Winooski River Valley.* These rivers, in the northern half of Vermont, rise in the *eastern* part of the State and pass through the Green Mountains, the former north of Mt. Mansfield, the latter just north of Camel's Hump; in the case of each, the bottom of the valley where the river passes the line of these mountains is not far from 4000 feet below their summits. The course of each is about N. 15°–20° W. and S. 15°–20° E.

Along each of these valleys, the glacial scratches are closely parallel to its main trend, as shown and recognized by the Vermont geologists. It is strikingly exhibited on a map of the State accompanying the report. On the Lamoille there are the courses S. 55° E. to S. 85° E.; on the Winooski, the courses S. 60° E., S. 80° E., and even east-and-west in one case.

4. *Otter Creek Valley.* Otter Creek flows northward along the great valley in the southern half of Vermont, just west of the axis of the Green Mountains, passing by Rutland, Brandon, Salisbury, toward the southern end of the broader part of Lake Champlain. Its general course is about N. 15°–20° W. and S. 15°–20° E. The glacial scratches in the valley have the courses S., S. 12° E., S. 15° E., S. 20° E.

5. *Merrimack River Valley* (New Hampshire). The conformity between the courses of the scratches along this valley above Lowell and its trend is well shown on the map of New Hampshire by Prof. C. H. Hitchcock. The average trend of the valley is but a little east of south, and the same is true of the scratches.

We have thus evidence of the existence during some part of the era of ice not only of a glacier movement in New England along the Connecticut river valley, but also of one along the upper Champlain valley, the Lamoille valley, the Winooski valley, the Otter creek valley, and probably the Merrimack valley; and many of the courses of scratches observed in other parts of Vermont and New Hampshire have divergences from the normal course of the great glacier, which are probably due to the valley-depressions of the surface. Among these smaller valleys are perhaps those of the Queechee, Black, Middlebury and White rivers of Vermont and the Deerfield of Massachusetts; for the existence of an *independent* glacier in each of these valleys is recognized as probable by Prof. Hitchcock, on the ground of the conformity between the direction of the scratches and the valley, although the iceberg theory is adopted by him for all the rest, even the Lamoille, Winooski and Connecticut. The writer has elsewhere mentioned the evidence in favor of a Hudson river glacier movement, and of another in the Mohawk valley running easterly through central New York; and further, of one along the St. Lawrence valley, the scratches in it following its course according to the observations of Dr. Dawson.

The facts are sufficient to prove that examples of valley movements of glacier ice must have been common over the continent in the Glacial era, or rather the rule for all the larger valleys. It is hence evident that no observations on glaciers are complete which do not take into account the surface features of the country. Prof. Hitchcock recognized the deflecting influence of the Connecticut and Lamoille valleys; but the deflection, in his view, was that of icebergs. Besides the argument against the iceberg hypothesis elsewhere presented, New England affords another in the fact that if there were, at the time, a submergence to the depth required to overcome the obstacles to a southeast movement offered by the southerly trend of the mountains, there would still have been no southeasterly flow of waters over its surface, since no currents having this course exist in the adjoining seas. And further, the necessity of helping out the iceberg theory by bringing in glaciers for some of the smaller valleys, because icebergs could not be supposed to have worked their way along them to do the scratching, affords another strong argument against it.

The question now comes up, whether the scratches in the valleys were made in the Glacial era while the glacier was of quite or nearly its maximum thickness, or during the decline of the glacier, when its thickness was so diminished as to make the ice of the valleys essentially independent glaciers.

With regard to the Connecticut valley ice, the following evidence appears to show that the movement took place while the continental glacier still had its continental, or at least its New England, movement. *a.* In Massachusetts and Connecticut the only scratches in the valley are those trending south or *west* of south, and they are often very deep; even the tops of Mt. Tom and Mt. Holyoke have only these scratches. This uniformity seems to prove that the direction of movement thereby indicated characterized the ice of this part of the valley through *the whole of the Glacial period.*

b. Again, if a local glacier occupied the valley having a thickness of say one, two, or three thousand feet, or such as would lie below the level of the Green Mountain summits, the glacier would have had through its breadth a nearly southerly course corresponding to the trend of the valley, and in that case southerly scratches should have existed over the whole surface, even localities remote from the Connecticut river—*where they are not found.*

In another place I have supposed that the southeasterly course which occurs in the scratches to the west of the Connecticut river might have been a resultant between the tendency to a southerly movement down the valley, and that down the slope into the valley. But this was so only to a very small degree. For the ice, after passing over the valley, resumed on the east its southeastward scratching.

c. In the part of the Connecticut valley north of Massachusetts, the course of the scratches is not that of the valley, but differs 10° to 15° from it to the *eastward.* This greater easting shows that the southerly movement of the ice induced by the valley was modified by some force pressing it eastward, and this force could only have been that due to the movement of the general glacier. Hence it proves that the general glacier existed at the time in nearly or quite its full force.

We may conclude, therefore, that the valley ice of the Connecticut had through its southern half (across Massachusetts and Connecticut) its own independent southward motion, mostly unmodified, during the whole progress of the Glacial era. But along the more northern part of the valley, there were the modifications in the valley movement just pointed out, and also scratches made by the general glacier. If the southeasterly scratches (those of the general glacier) should be found to be the older of the two sets, we should infer that when they were made the general glacier was then the thickest; but the facts would not prove that the thickness had been so far diminished as to leave the Connecticut valley glacier wholly an independent one. Prof. Hitchcock has stated as his belief that the southwesterly scratches were the oldest, but admits that there is much doubt with regard to it.

This movement of the bottom of a glacier six or eight thousand feet thick along a different course from its main mass wherever it lies in great valleys, is a necessary result of mechanical law. It moves just as thick pitch poured over a sloping surface in which there are a few large groovings would move, the mass following the general surface, and the portions in the grooves nearly or quite the course of the grooves. The thickness of the ice that followed the course of the valley was at least 2000 feet; for the southerly scratches occur not only on the summits of Mt. Tom and Mt. Holyoke, but also on the top of Mt. Pocomptuck in Heath, 15 miles west of the Connecticut, the height of which, as stated, is 1888 feet.

As to the Lamoille, Winooski and Otter creek valleys, the case is somewhat different; for if the movement of the ice in the valleys took place when the great glacier was in full force, it was a movement in each *up the valley.* The valleys are, however, of gradual slope—that of Otter creek extremely gradual—and facts show that the ice is often moved up slopes many hundreds of feet. Dr. A. S. Packard, Jr., mentions the occurrence of fossils in the drift on Mt. Katahdin (Maine) at a height of 4000 feet above the sea, which must have been brought from the low country to the north where such fossils are found in place. As Dr. Packard observes, such facts show that icebergs were not the transporting agents.

It is, however, possible that each of these three valleys had its independent glacier during the melting of the ice. But if so, the great glacier must have been removed wholly out of the way of the valley glacier, so as to be no impediment to its movement down the valley; and it seems probable, from the small extent of these valleys, that by the time the general glacier had got out of the way, the valley ice would also have mostly disappeared. It is quite probable that a careful study of the scratches along one or another of these valleys may decide this interesting question.

It seems to be a natural consequence of a gradual melting of the great glacier, that sooner or later parts of the ice should have become independent and taken independent movements. We should naturally look for this independence at least in the large valley of the Connecticut river. A thinning of the ice to 2000 feet would necessitate, it would seem, a valley movement southward. And yet, as has been observed, the evidences of such a glacier movement do not exist—that is, the scratches are confined to so narrow a band along the center of the Connecticut valley as to show that they were not made by an independent Connecticut valley glacier. How then can we reconcile the fact that the ice must have thinned down to 2000 feet, 1000 feet, and so on, and yet had no movement as a separate glacier? The explanation is this:—The melting of the ice took place in the early part of the Champlain era—an era of subsidence for New England and a large part of the continent (and therefore favorable to the melting); and this subsidence was greatest in New England to the north, having been at least

325 feet in the latitude of Burlington; nearly 150 feet near the northern boundary of Massachusetts, one hundred miles from the termination of the valley (the highest terrace on the river in Hinsdale, New Hampshire, being 159 feet above the river, according to the Vermont Report); and 45 to 50 feet at New Haven, the southern end of the Connecticut valley. Such a subsidence would have diminished the average slope of the whole valley about *one-and-a-half feet a mile.* For the southern half, from northern Massachusetts to Long Island Sound—100 miles—the slope, which now averages *two* feet a mile, would have been reduced to *one-and-one-tenth* of a foot a mile; and from Springfield down, which is 60 miles from the Sound, and the height of the water level only 64 feet above the Sound, making the average slope below about one foot a mile, and where the Champlain subsidence was at least 60 feet more than at New Haven on the Sound, there would have been no appreciable slope in the waters; the basin, as it is designated by Hitchcock, from Middletown in Connecticut to Holyoke in Massachusetts, would have been strictly a basin.* Under such circumstances the ice along the valley would have lost all motion. The same condition of rest would have belonged to the ice of other north-and-south valleys of as small rate of descent; but not necessarily to east-and-west valleys like the Lamoille and Winooski.

High up even the north-and-south valleys, where the slopes were not sensibly changed by such a subsidence, local glaciers might well have existed. Evidences of them in the region of the White Mountains have been pointed out by Dr. A. S. Packard, in an excellent memoir on the Glacial Phenomena of Labrador and Maine (94 pp. 4to), published in Volume I of the Memoirs of the Boston Society of Natural History (1867); also by Professor Agassiz, in the American Naturalist for November, 1870, who states that he observed the marks of local glaciers in the White Mountain region in the year 1847, soon after his arrival in this country.

In the foregoing pages the facts from the State of Maine have not been referred to. These are well discussed by Dr. Packard in the memoir just referred to, in which he recognizes and applies the principle discussed in this and the writer's former papers on the valley glaciers. He observes that of the eighty localities of scratches that have been noted in Maine, the scratches in sixty-two have a southeasterly course: that the southeasterly course of the glacial grooves and striæ is especially marked in the interior of the State on the high lands and low mountains; but, approaching the coast, the evidence shows that the glaciers moved down the river valleys, and thus assumed a more north-and-south course, and at times, owing to local trends in the depressions, were even deflected so as to flow in a direction a few degrees west of south. The facts in Maine are just such as are general to New England.

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* In order to deduce the amount of subsidence for any place on the river from the height of the highest terrace above the ordinary level of the river, it is necessary to deduct first the height of the lower flats. This would give for the amount at Hinsdale 138 feet, which is 88 to 93 greater than at New Haven; and for the amount at Springfield, where the highest terrace is 136 feet, it would give 115 feet, or 65 to 70 feet greater than at New Haven. Such calculations may be in error, and generally will give less than the actual amount, because the height of the terrace depends on the amount of *excavation* that has taken place since the land reached its present level; and this is in most cases less than the amount of elevation.

The same principle is recognized by Prof. N. S. Shaler in the Proceedings of the Boston Society of Natural History, for 1870. Other similar facts have been recently pointed out in States to the west of New England. When the applications of the principle are studied out over the whole continent, we shall understand better than we now do the sources of the varied movements in the great glacier.

Glacier Scratches along valleys. (Appendix to Art. XXXII.) —Prof. Emmons, in his N. Y. Geological Report (1842) at page 422, says that the direction of the glacier scratches in northeastern New York "conforms to that of the great valleys; in the Champlain valley it is north and south; in the St. Lawrence valley, southwest." The particular localities where his observations were made are not mentioned. He describes deep and broad channelings of the Trenton limestone west of Watertown, on Black River, which have a southwest course, and extending to the shore of Lake Ontario, a distance of ten miles; and states that the scorings of the rocks are parallel to the valleys, which here run southwest. Among western observations on this point not published in this Journal, are those of Prof. C. A. White in his Iowa Report, and those of Dr. Newberry.

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ON THE

POSITION AND HEIGHT OF THE ELEVATED PLATEAU

IN WHICH

THE GLACIER OF NEW ENGLAND, IN THE GLACIAL ERA, HAD ITS ORIGIN.

By James D. Dana.

THE existence of a region of high elevation in northern America as the source of a continental glacier in the Glacial era has often been assumed, but rather because the glacier theory was lame without it than as a result of special research with respect to the extent and location of such a region. I do not propose, at the present time, to treat the subject continentally, but simply to discuss the question as to the origin of the New England glacier. If I mistake not, however, the discussion, so far as it goes, meets the requirements of the continental question, while it proves that the idea of one central glacier source for the continent is without foundation.

1. *Position of the elevated plateau.*—In my paper of last month, on the "Valley Movements of Glaciers," (p. 233) I mentioned the fact, from the observations of the Vermont Geological Survey, that the glacial scratches on Camel's Hump, Mt. Mansfield and Jay's Peak, three of the high summits of the Green Mountains in the northern two-thirds of Vermont, have a course of about S. 50° E.* In the White Mountains, 70 miles to the south of east (S. 75° E.), the direction of the scratches near the Lake of the Clouds, on the north side of Mt. Monroe, is, as I am informed by Prof. C. H. Hitchcock, at points from 5000 to at least 5200 feet above the sea, in different places, S. 34° E. and S. 54° E. (S. 20° E. and S. 40° by compass); on the north side of Mt. Clinton, 4430 feet high, (one of the White Mountain series of summits about 17 miles west of Mt. Washington), near top, S. 50° E.–S. 54° E.; and on the south peak of Mount Clinton, at a level of 4320 feet, S. 54° E. He observes further that boulders occur at a height of 5800 feet on the north side of Mt. Washington.†

These scratches, and others crossing the Green Mountains, could not have been made with the land of North America at its present level. Elevated land must have existed to the north, if they were the work of glaciers. Moreover, these scratches on the higher summits of New England, must point approximately toward the region of elevated land, or the great Icy Plateau, as we may call it, on whose slopes the movement of the glacier originated.

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* According to the Vermont Geological Report the direction of the scratches on Camel's Hump is S. 50° E. (S. 40° E., compass), on Jay's Peak, S. 50° E., and on Mt. Mansfield, situated between the two, S. 30° E., S. 55° E., S. 58° E., at different points.

† Prof. Hitchcock observed also the course S. 24° E. near the Lake of the Clouds, but it was not common; also, in the saddle between Mt. Pleasant and Mt. Franklin, 4400 feet above the sea level, S. 34° E.; and the same in the gap between Mt. Pleasant and Mt. Clinton, 4050 feet high. It would therefore appear that the course of the general glacier over the White Mountain region was about S. 55° E., and that there were variations from this course due to the lay of the land.

This seat of power in the era of ice was not the Adirondacks; for these stand (as will be seen on any map of North America, and even a map of the World) much too far to the south. The scratches point over Lake Champlain and the low hills and plains beyond, and across the St. Lawrence. On the other side of this river lies the large valley of the Ottawa, and it is almost exactly in their direction ; and the prevailing trend of the scratches through its lower half is about S. 45° E. According to the table in Logan's Report for 1863 (p. 890), this is the course at Ottawa City, Hull, Rideau River at Stegman's Rapids, and Horton near Renfrew village south of the Ottawa. At Allumettes Lake, the course S. 25° E. was found; but this locality is higher up the stream, and the course may well have been due to some local influence. There can be no doubt that, if the Glacial era was a *glacier* era, the Ottawa valley ice was a part of the same great ice-stream with that which crossed the Green Mountains, but a portion nearer the source.

The Ottawa valley, including that of Montreal River (which has the course of the Ottawa and is its western head-tributary), extends to a point nearly 500 miles in an air-line from Mt. Mansfield, and 570 from the White Mountains, with an average trend of S. 65° E. But the source of Montreal River was not the source of the glacier movement; for the course of the scratches in the Ottawa, instead of corresponding with the trend of the valley, is, as stated, S. 45° E. The scratches point, therefore, to the eastward of the western source of the Ottawa, and at least as far east as the region northeast of Lake Temiscamang (the main source of the waters of the Ottawa), on the watershed between the St. Lawrence valley and Hudson's Bay. The scratches of the White Mountains and Green Mountains and those of the lower part of the Ottawa valley point alike toward this area.

It follows that the Icy Plateau, whence the great glacier took its departure, must have existed either about this part of the Canadian watershed, or in the same direction farther to the northwest; and since the line of the scratches, if carried farther to the northwest, would strike Hudson's Bay, or its western border, it is probable that this watershed was the actual position.

This view accords with the great diversity of direction in the scratches about Temiscamang Lake, they varying, according to Logan, from S. 78° E. to S. 7° W., the least easting being found on the *west* side of the Lake ; the observations are, at East Bay, S. 53° E., S. 78° E.; on the east shore S. 38° E., S. 18° E.; at West Bay, S. 15° E.: on the west shore, S. 35° E., S. 18° E., S. 14° E., S. 1° E., S. 7° W.

The courses of the scratches on the heights of northern Maine (S. 59° E. on Mt. Abraham, C. H. Hitchcock) also favors this conclusion. Again, in the part of Canada, north of northeastern Maine, on the Madawaska River, about Temiscouata Lake, Logan found scratches trending S. 54° E., S. 52° E., S. 55° E., S. 66° E., S. 48° E., S. 60° E., (with one of S. 27° E.); and these courses, if the form of the surface has not increased the easting, would point to the same watershed and the part lying between Temiscamang and Mistissinny Lakes, but nearer the latter, and these lines continued would strike into Hudson's Bay, and this is additional proof that the high land was along the watershed.

Again, the courses of the scratches in western New York and on Lake Huron and Lake Nipissing (northeast of Lake Huron and south of Lake Temiscamang), have considerable *westing*. On the north shore of Lake Huron the course is mostly S. 13°-22° W., according to Logan; on the Georgian Bay (northeastern side of Lake Huron), S. 37°-45° W.; at the southeast bay of Lake Nipissing, S. 35° W; in western New York, S. 35° W., according to Hall. This prevalent *westing* points toward the same region northeast of Lake Temiscamang along the Canadian watershed, and seems to shut off from consideration regions farther north or west.

Taking into view all the observations here cited, we may conclude with much confidence that the region of greatest elevation along the watershed, or that of the Icy Plateau, was situated between Lake Temiscamang and Lake Mistissinny; and that its trend was consequently northeast and southwest, this being nearly that of the watershed between the lakes—a trend just right for a southeast movement of the ice.

Over the higher parts of the Green Mountains, *south* of Vermont, the amount of easting in the scratches diminishes southward, their direction being S. 40°-45° E. in northeastern Massachusetts; about S. 30° E. in southeastern Massachusetts; and about S. 25° E. in Connecticut and in eastern New York adjoining. These directions correspond well with the position assigned to the Icy Plateau. But as the Adirondacks lie between the two, it is not possible to say how far the courses may have been dependent upon these New York mountains.

2. *Height of the Icy Plateau above the sea.*—The higher summits of the Green Mountains are, according to Guyot, between 3800 and 4430 feet in elevation, the latter being the height of Mt. Mansfield. Killington Peak, 60 miles south of Mt. Mansfield and east of Rutland, is 4221 feet high (Guyot). The average height of the range, according to the same authority, is

about 3500 feet. The distance from Mt. Mansfield to southeastern Massachusetts is about 200 miles. The scratches of this mountain point southeastward toward the upper Merrimack valley; and those of this valley and of the adjoining region, down this valley in the direction of Boston Bay; and to this bay the distance from the summit of Mt. Mansfield is but 175 miles. Still, taking 200 miles as the length of the old glacier from Mt. Mansfield to the sea, and 3500 feet as the average height of the Green Mountains in Vermont, *the average rate of descent in the land is 17½ feet a mile*, and 20 feet a mile from the summits of the higher peaks. This was consequently the amount of slope that contributed toward the movement of the glacier over a large part of New England.

To have moved the same glacier from the northwestward *across the Green Mountains*, and to have abraded their highest summits and also scored surfaces on the White Mountains that are full 5200 feet above the sea, the propelling slope, or those of the Icy Plateau, must have certainly been higher than 5200 feet. We cannot assume that the rate of descent from the top of the Icy Plateau to the 5200 foot level on the White Mountains, a distance of about 400 miles, was as great as seventeen feet a mile; but we may reasonably infer it to have been at least *three* feet. This rate for 400 miles would make the height of the Plateau to average 6400 feet. The watershed is now about 1500 feet above the sea; accordingly, the average height of this region should have been at least 4900 feet greater than now.

A grade of *two feet* a mile would diminish this estimate 400 feet, making the required average height of the Icy Plateau 6000 feet.

The facts, therefore, demonstrate that this Canadian watershed was greatly higher—at least 4500 feet on an average—than at present. It is not supposed, or supposable, that the region was the course of a range of crested mountains that have since been washed away. No facts connected with glacial denudation, or that of subsequent time, favors such an extravagant assumption. All that the case demands is simply a bending upward of the surface over a wide area through a general continental movement of the crust having its greatest results to the north; and such we may believe it to have been. Similar oscillations of surface upward, and again downward, have taken place through all geological time, and they are still in progress; and geologists have detected them on some sea-shores where there is a standard water-level for comparison.

Moreover, the work of lifting continents and raising mountain chains went forward on a stupendous scale over Europe, Asia, and both Americas, through the whole era of the Tertiary; and this later upward movement in the higher latitudes of the continent followed on as the close of the long series, all the preceding elevations, as well as the last, being in preparation for the Glacial era.

Such an *upward* bending is no more improbable than the *downward* bending which the Iceberg theory of the drift assumes to have taken place; and even less so, *since* the latter must have been greater in *vertical change* of level, and also vastly wider in its limits from north to south; and moreover such an event would have been out of joint with the times, tending to ameliorate instead of giving arctic vigor to the climate. And further, as I pointed out many years since, (this Journal, II, vii, 379, 1849,) there is independent proof of a high-latitude elevation of the continent during the Glacial era, in the fact that the drift latitudes are also *fiord* latitudes,—the fiords occupying valleys of erosion by fresh water or ice, which could have been made only when the land was far above the present level.

A bulging of the crust in any region to a height of 4,500 or 5,000 feet above its present level would have carried up the part of the continent adjoining to a greater or less extent. If the above use of fiords is right, they may help us, wherever they occur, in arriving approximately at the amount of elevation in the Glacial era along sea borders. From the depth of those of Maine,—mostly 100 to 150 feet—we thus learn that the land along this coast was at least 150 feet higher than now, and probably 200 feet. Other facts lead us to believe, as stated by the writer in his paper on the Geology of the New Haven region, (Mem. Acad. Conn. ii, p. 45,) that Southern New England was 100 to 150 feet above its present level. Hence, the coast line of New England would have been much extended outward by the change of level. Long Island Sound would have been reduced to a narrow channel, and Long Island joined to Connecticut, to which it geographically belongs. St. Lawrence Bay would have been greatly contracted, and the St. Lawrence River lengthened seaward over part of its present site. Lake Champlain would have poured its waters down the valley of the Hudson; and, as others have shown, Lake Michigan down the Mississippi valley.

The elevation of New England would have increased in amount from the southern shore northward, and from the southeastern northwestward, toward the Icy Plateau. Consequently the White Mountains, Mt. Mansfield and other Green Mountain peaks, and the Adirondacks of northern New York, would probably have stood at least 500 feet above their present level. If so, it is necessary, in order to have the slope of one averaging two or three feet in a mile, that as much at least should be added to the average height of the great northern Icy Plateau, which would make it 6,500 to 7,000 feet.

If the Icy Plateau, instead of being along the watershed, was situated to the north and northwest of it, somewhere in central or northern North America, the height must have been greater in proportion to the remoteness.

3. *The movement of the Glacier.*—The great glacier moved southeastward (the Icy Plateau trending northeastward) down the valley of the Ottawa and the slopes east of it, and marked its course deeply in the subjacent rocks. But on nearing the St. Lawrence, the lower part of its mass yielded to the impulse of gravity according with the slopes of this transverse valley, so that along this valley only *southwest* scratches were made, as facts show. Yet, the upper part of its mass continued on its first course, and, in northern New York and Vermont, and over southern Canada adjoining the latter State, the southeastward moving ice again touched bottom and resumed its work of abrasion. This is precisely parallel to what happened to the glacier, as I have shown, in its passage across the Connecticut River valley. In each case the valley determined the movement along its course of an under portion of the glacier, while the upper portion, spanning the valley, continued the grander movement initiated in the Icy Plateau, and favored by the general slope of New England. The great glacier, 6,000 to 8,000 feet in thickness, had no difficulty in keeping on its course according to the general slope of the land, and, at the same time, in following underneath the larger valleys or even many of the local slopes. It could not do otherwise. Icebergs in a continental sea, on the contrary, would have been puzzled to find all the criss-cross currents needed to help them along the valleys, up hill and down, and through all points of the compass.

4. *One cause of the cold of the Glacial era in North America.*—Increase in the extent and height of high-latitude lands may well stand as one cause of the cold of the American Glacial era. This rising of the land of northern Canada into a great plateau, at least as high as the summit of Mt. Washington, with the less elevation of wide regions north and south as a part of the great swell of the surface, and with the simultaneous elevation of other, perhaps higher, plateaus over the more northern and northwestern portions of the continent, and all a sequel to the majestic uplifts of the Tertiary, would have made a *Glacial* period for North America, whatever the position of the ecliptic, or whatever the eccentricity of the earth's orbit, though more readily of course if other circumstances favored. Having the most elevated land of eastern North America along the region pointed out, the courses of the winds and the distribution of moisture would have been different from the present. Canada being then on the *seaward* slope of the high land instead of, as now, on the landward slope, could not have had its comparatively dry climate with only an annual fall of 30 inches of moisture.

5. *Epochs of the Quaternary in North America.*—In view of the facts with regard to the elevated northern lands of the Glacial era here set forth—facts if Glaciers had anything to do with the Glacial phenomena—the epochs of the Quaternary, before deduced by the writer, come out in great boldness.

The movement of the GLACIAL era carried the northern lands upward, at least 5,000 feet above their present level in northern Canada, and probably as much or more over the higher latitudes to the west and north.

Then followed a slowly progressing subsidence—the great characteristic of the CHAMPLAIN era—which ultimately sank the same lands even to a greater extent than they had been raised, placing the valley of the St. Lawrence, about Montreal, over 500 feet below its present level, and probably 1,000 feet at least below its level in the Glacial era With the commencement of this movement, or as it progressed, began the melting of the glacier; but the era continued, as proved by elevated beaches full of shells and other deposits, long after the melting ceased. During it, owing to the larger amount of subsidence to the north, north and south rivers had their slope greatly diminished, and in some places leveled out entirely for long distances; and owing to the vast depositions of drift, rivers, like Niagara, sometimes had their channels obstructed and were forced to begin new cuts, while other water-courses of the Glacial era were wholly cut off, as that from the Champlain Lake down the Hudson valley.

Afterward the return movement, that of the TERRACE era followed, placing the land finally at its present level, leading thus to a deepening of river channels, and thereby to the making of the river and lake terraces that cover the continent.

The fact of these grander movements which mark the three eras does not preclude the possibility of minor local oscillations of level during their progress.

From the Author.

[From the American Journal of Science and Arts, Vol. V, March, 1873.]

ON THE GLACIAL AND CHAMPLAIN ERAS IN NEW ENGLAND.

By JAMES D. DANA.

[FROM THE AMERICAN JOURNAL OF SCIENCE AND ARTS, VOL. V, MARCH, 1873.]

ON THE GLACIAL AND CHAMPLAIN ERAS IN NEW ENGLAND.

BY JAMES D. DANA.

THE following brief statement of some of the views I have been led to entertain, with regard to the Glacial and Champlain eras in New England, is here presented to close up my contributions on the subject and help forward discussion. It may also serve a good turn by preventing a waste of energy in combating misunderstandings, such as occurred not long since.[*] Fuller illustrations with regard to most of the topics, supplementary to those in my Manual of Geology, will be found in my Memoir on the Geology of the New Haven Region, in volume ii (1870) of the Transactions of the Connecticut Academy, and in papers in the volumes of this Journal for 1871. On one point, the height of the icy plateau in which the glacier-flow over New England had its head, (treated in vol. ii of this Journal, p. 324, 1871,) I give additional observations with a modification of my former conclusion.

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[*] Proceedings of the Boston Soc. Nat. Hist., vol. xv, p. 48, 1872. The "strictures" of the author (read before the B. S. N. H. in 1870) "on Dana's Geology of the New Haven region" are, for the most part, not on my views but on his unfortunate misunderstandings of them. In the commencement of his remarks on the Post-tertiary, he says that the Post-pliocene of Lyell corresponds to my Terrace or Recent era —the third division of the Post-tertiary; when, in fact, as my Geology shows, it is very closely equivalent of the Glacial and Champlain eras, or the first two divisions. In another place he states that the Champlain era seems to have been, in my view, one in which the ocean extended over the most of New England beneath the glacier, and the deposits made were chiefly marine:—when I have opposed both views in my memoir as well as my Geology, and have made the era that of the most extensive freshwater formations in the world's geological history. Again, he remarks that I refer to the Terrace era the terrace deposits of the river valleys and sea-shores; when, as just stated, I make these preëminently the Champlain deposits, and include in the Terrace era only the *terracing* of the Champlain beds, and the formation of some superficial deposits. Then, having made my "Terrace or Recent" era to cover a large part of the Champlain era, he institutes for the rest—the *Recent* part in his view, which he supposes I wrongly annexed to the Terrace era—another grand division of the Post-tertiary and provides it with a name; which grand division is essentially identical in its deposits with the whole of my "Terrace or Recent" era. This "comedy of errors" relates to subdivisions which are explained at length in my Geology and adopted in the memoir.

Other examples of the misunderstandings that pervade the article might be mentioned; but these are enough.

I. The Glacial period (that of the great glacier) was an era of transportation by ice, with the deposition from the glacier of only a small part of the drift, including the boulder clay; while the early part of the Champlain period, to which I refer the time of melting, was an era eminently of deposition, and also of further transportation by moving waters and floating ice.

II. The Glacial period was very long. Supposing, as I have done, one foot a week as the average rate of movement—perhaps too large an estimate—10,000 years would be required to carry a boulder one hundred miles, the distance from the northern boundary of Massachusetts to New Haven, Ct.; and how many times one hundred miles were passed over by the ice has not yet been deciphered. The progress of the melting of the glacier was for the greater part exceedingly slow; but at the close, or for the lower 500 feet, relatively rapid.

III. The general course of the movement over New England was to the southeastward. But in the larger valleys there was often a more or less perfect conformity to the course of the valley; showing that the movement of the lower part of the glacier was determined, in some degree, by the slopes of the surface beneath—just as thick pitch, descending a gently-inclined board that has large oblique furrows in its surface, would follow the general slope of the board, but have a part below diverted by the furrows. The direction of movement was determined by the general slope of the upper surface of the glacier; and this depended on the distribution of precipitation and temperature, and the position of the region of freest discharge, as well as the general slope of the land; but the influence of the valleys beneath was the same, whichever of these causes was predominant.

IV. Since the glacier was spread widely over the country and had no overhanging rocky walls or peaks, its stones and earth must have been gathered into its lower part where it lay in contact with the earth's surface. It brought to the New Haven region masses of trap, of all sizes, from small pebbles to boulders of 1,000 tons, and these must have been taken up for transportation from the trap ridges of the Connecticut valley, nearly all of which are under 1,000 feet in height above the sea. It also brought masses of sandstone from the lower hills or plains adjoining; and from veins in the rocks dug out pieces of native copper, which were dropped on the way; one such, found within two years past, a few miles north of

New Haven, weighing nearly a hundred pounds. These are mentioned as examples of what occurred everywhere. The whole surface of the country, from the slopes of the higher mountains to the low plains, contributed to its load, the glacier making much loose material by abrasion where it found none at hand. Moreover, part of this material was gathered up within a few miles of where it was deposited.

Having a thickness of 5,000 to 6,500 feet in northern New England and an average of 2,700 in southern, the pressure on the surface beneath was immense; 6,000 feet corresponding to at least 300,000 pounds to the square foot. Under this great pressure there was not only abrasion of the rocks beneath by the ice armed with stones in its lower surface, and also a crushing of softer kinds from mere pressure, but, besides, a breaking and crushing of the ice itself against the obstacles in its course, and also a pressing of the plastic material down among all the stones and gravel or sand; and thus it was able to envelop and take up into its mass the loose material.* Further, the ice of the ice-mass above must have been forced down into all openings and crevices in the rocks, so that the glacier, as it moved, had tremendous power in prying off and abrading, and must have made boulders and gravel—its chips—in immense quantities for transportation. Such work is more readily done by a continental glacier 2,500 to 6,000 or more feet thick, than by one of 500 or 1,000 feet confined in an Alpine valley; for the power of erosion increases almost exactly with the thickness of a glacier.

In consequence of the conditions just stated, the stones and earth which the glacier bore along were contained mostly within the lower 1,000 feet, and probably the larger part in the lower 500.

V. The larger rivers of New England may have continued to flow through the whole of the Glacial period, though, to the north, with diminished volume. The existence of such a period demanded only that through a long succession of years the melting in the warmer months should have carried off each year *only a part* of its snows, so that an annual addition was made to the accumulation in progress. A fourth, or a third, or more of the snows that fell each year may have melted to descend through the crevasses, and if so the streams would have been sufficiently well fed, independently of the contributions of springs, to have kept up their flow under the mantle of ice,

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*** In experiments by Christie, and also by Tyndall, ice has been moulded into various shapes by pressure; and Tresca has produced, by forcing it through holes, long cylinders, the ice in the operation not losing, he states, its glassy texture or aspect.**

and to have performed, to some extent, their ordinary work of erosion and transportation. Their loss from evaporation would have been very small, in their cold covered ways. As freedom from melting is not probable, so the existence of such streams may be reasonably assumed. (See, further, pages 10, 11.)

VI. The melting of the glacier was brought on by a general amelioration of the Glacial climate,—probably consequent upon a diminution of the elevation of land over the higher latitudes, sinking this part of the continent below its present level (see beyond, p. 211). It went on over the general surface of the glacier, and not merely at its southern edge, though of course diminishing in rate to the northward. When the average thickness of the ice over a region was reduced to 1,000 feet, the stones and earth that had been in the ice above were now in this remaining portion; and so for 500 feet, etc.; and consequently, toward the close of the melting, very large quantities of drift must have been set free together. Sooner or later, the waters from the melting ice, descending through the crevasses or other openings, would have made streams in all the valleys, even those now dry, and lakes wherever there was no outlet, besides enlarging greatly the rivers and lakes that may have held their places through the Glacial era. There was thus, over the continent, water as well as dry land to receive the gravel and sand thrown down, and water also along the sea-border. The melting would have gone forward with increasing haste as the thickness of the ice lessened; and all the streams would thereby have become flooded far beyond modern experience, and consequently the work of transportation and deposition would have been vastly accelerated.

VII. The conditions attending the melting of the glacier being such as have been just specified, the earth and stones that fell over the dry parts of the surface would have been *unstratified;* while the part which fell into moving waters should have varied in the degree of stratification received according to the depth of the waters, and their rate of flow, and also according to the kind of material thrown in and the rate of its supply. If the earth fell in too great quantities for the waters to work over and arrange, there would have been produced only imperfect stratification, or none at all beyond a levelling off at top; while, with a more gradual supply, or a fuller flow of waters, the stratification would have been regular and general. Very rapid currents would have made layers in the formation that were obliquely laminated, the hurrying waters pushing up the sands before them as deposition went on; and where the supply of earthy material from the unlading glacier was very large and the waters abundant, the obliquely laminated layers thus made ought to have been a foot or more in thickness; for each such layer is necessarily the result of a single onward rush of the waters. Where plunging waves accompanied the rapid flow, the resulting layers would have been composed of wave-like parts, each independently laminated.* In quiet waters, the deposits should have been of all degrees of fineness and regularity down to those of clay.

The older terraced alluvium or stratified drift of the valleys of New England presents in its various parts all the different kinds of deposits here described. The material is generally stratified. Much of the alluvium over the interior has at intervals beds that are obliquely laminated; but this characteristic is most common toward the coast. The terraces of an estuary, like that of New Haven, are only the terminations of those of the river valleys which open into the region about the estuary; and the latter are identical in character with those over all New England, and part of one and the same system.

VIII. The depositions along the valleys and estuaries continued to increase in extent, long after the melting of the glacier was ended, through contributions from the unstratified drift which lay loose in immense quantities over the hills; and afterward, during the rest of the Champlain era, it went forward more slowly, from the ordinary operation of fluviatile, lacustrine and marine waters.

IX. The facts afford the following argument in favor of some of the views above stated.

(1) The prevalent stratification of the old terraced alluvium over New England is evidence of its *sedimentary* origin. (2) From the vast width of many of these alluvial regions, we infer an extraordinary flow of waters over the country. (3) The great thickness of the deposits, rising in some places, for long distances, to two hundred feet or more above the river, and no doubt originally filling the valley to the level of the upper terrace; and still more, the frequent occurrence of thick obliquely-laminated layers—one such in the New Haven region, reaching the extraordinary thickness of eight feet,—are indications of a very rapid and abundant supply of sand and gravel; and the beds of coarse stones, often intermingled, tell of currents of immense power, or of sudden falls from the floating or overhanging ice. (4) As the vast flow of waters and the vast flow of sand and gravel were concurrent events, and since the era of deposition immediately followed that of the great glacier, it seems to be a most natural inference that the final melting of the glacier set free both the water and the stones and earth.

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* **Several of these points are illustrated in my Memoir on the Geology of the New Haven region. Layers of this composite kind characterize much of the "Orange Sand" in northern Mississippi, as represented by Prof. Hilgard in his Geological Report on that State, who has shown that this formation is in all probability only stratified drift.**

(5) The extent of the floods throughout New England, as proved by the extent and character of the deposits, also indicates that the melting of the glacier did not occur only at the southern margin, so creeping slowly northward, but simultaneously over its wide extended surface; and if so, the melting of the glacier must have been due to a general decided amelioration of the continental climate, as above stated.

X. About the head of New Haven bay the terrace-plain has a height of from 40 to 50 feet above the sea. It is every where stratified, and the beds are generally obliquely laminated. The laminæ of the obliquely laminated layers dip southward, that is, rise to the northward, and thus show that they were deposited under the action of currents from the south, those of the incoming tidal waves. But at the entrance of the river valleys or where the river valleys merge into the region of the New Haven plain, at a level about 20 feet from the top of the deposits, (and 20 to 25 above the present sea level,) there is an abrupt change in the direction of the oblique lamination, the layers above this level rising *to the south* instead of to the north. Here is proof that a river flood had then set in that controlled the depositions in spite of the force of the incoming tidal currents. That the waters of this flood came loaded with sand and gravel in enormous quantities is indicated by the thickness of the obliquely laminated layers; that there were plunging waves in the estuary connected with both the incoming tide and the flood, is made manifest by the composite character of these layers.

XI. In the Glacial era, the land over the higher latitudes probably stood *above* its present level.

The occurrence of fiords, both in the northern and southern hemispheres, in the Glacial latitudes, is favorable to this view, as I have elsewhere stated. For they show at least that during their formation the land in these latitudes was elevated above the present water level, when more to the south it was not so; and, therefore, that the cause of the change of level was not one affecting alike the whole globe. But these fiords may have been begun long before the Glacial era, in earlier periods of elevation. No Cretaceous or Tertiary deposits occur along the American coast north of Cape Cod, while they are present to the south and thicken southward. This fact is evidence that in those eras the continent to the north was higher than now, and the part to the south lower. It also suggests that these fiords may then have been forming. It is possible that they were then finished; but the condition of level in the later Tertiary being as above stated, when land and mountains were in progress of elevation over the globe and the cooling of the earth's climates was consequently going on, it is no forced supposition that it continued so to be through the following era in which the cooling reached its maximum; and probable also that there was some increase of difference between the level of the north and south corresponding somewhat with the increase of cold.

XII. The scratches of eastern Canada, of the high land of northern New England, and of eastern and western New York and northwestern Canada, point to a part of the Canada watershed between the St. Lawrence and Hudson bay as the head of the glacier that moved southeastwardly over New England.* The large valley of the river St. Lawrence, over 300 miles wide between the watersheds on either side, and trending east of northeastward, afforded no discharge for the ice; and this is proof that the summit-surface of the glacier about the mouth of this river, or over the St. Lawrence bay, was somewhat higher than over the watershed to the west.

In order that the glacier ice should have flowed over the whole line of the barrier or watershed bounding the St. Lawrence valley on the south, the level of the ice over the Canada watershed must have been the higher; and so also that in the St. Lawrence valley, for the first result of the movement would have been to raise the level of the valley ice to that of the barrier in front, the law of flow being, according to the generally accepted view, much like that of a stiffly viscous fluid. But that the glacier should have abraded the White Mountain slopes 5200 feet above the sea level, and carried boulders up the north slope of Mt. Washington to 5800 feet, the ice should have stood in that region about 6000 feet above the sea. The swell of the surface from which the White Mountains rise has a height, according to Guyot, of about 1000 feet above the sea; consequently the thickness of the glacier in that part must have been at least 5000 feet; and the facts observed do not need for explanation greater thickness than this. To the northwest, north, and north-northeast of the White Mountains, over the plateau about the headwaters of the Connecticut, the general level is about 1500 feet above the sea, which would make the upper surface of the glacier, in that region, if it were of the same thickness, about 6500 feet.

But we have the means of arriving at a more certain conclusion with regard to the last mentioned altitude. The slope of the upper surface of the glacier from the northern borders of New England southeastward in the line of flow would have been, according to the laws of fluids, very nearly uniform; and its average amount would have depended on the distance of the terminal margin in the ocean. The distance from the White Mountains southeastward to the coast of Maine, near Portland, and south of it, is about 80 miles. Supposing the glacier to have extended out 50 miles to sea, making the whole length 130 miles, and to have faced the ocean with a cliff 500 feet high, the rate of slope from the level at the White Mts., 6000 feet, would have been 42 feet a mile (or 1 foot in 126). If it extended on 150 miles to sea, to the range of shallow water between Cape Cod and the banks lying just east of Nova Scotia, as is more probable, the inclination at the surface would have been 24 feet a mile (or 1 foot in 220). Taking the latter as the slope, and extending it back from the White Mountans to the northern border of New England, or the southern margin of the great St. Lawrence basin, a distance of about 80 miles, we find for the level over this border region about 8000 feet, or 2000 feet above that of the White Mountains.

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* See this Journal, III, ii, 324.

The following courses of scratches in Canada just north of the mountains of northern New England, are cited from Logan's Report on the Geology of Canada for 1863. In Sutton, S. 36° E.; Orford, S. 43° E.; Sherbrooke, S. 43° E.; in lat. 47° 44′, long. 69°–69° 12′, S. 49°–64° E.; near Lake Temiscouata, lat. 47° 35′ to 39′, and long. 68° 39′ to 49′, S. 48°–54° E., with one observation of S. 27° E.; on Madawaska river, lat. 47° 22′, long. 68° 19′, S. 60° E.; at Trois Pistoles, near the St. Lawrence, lat. 48° 7′, long. 69° 8′, S. 32° E. These courses are cited here, not to prove the convergence alluded to, but to show that the system of movement was the same north of the high northern New England border as south of it.

The region between this northern border of New England and the Canada watershed was literally a great basin with the southern margin the higher. The actual height of the ice over this watershed required to cause a flow across it into New England, and to produce at the same time abrasion at bottom, we have no means of calculating. The slope of the nearly even upper surface across could hardly have been less on an average than 10 feet a mile; and, as the distance is 500 miles, this slope would give for the height of the surface of the glacier over the watershed 13,000 feet. This slope over the St. Lawrence valley would have gradually fallen off into that of the New England part of the glacier.

The average height of the watershed is about 1,500 feet; and this gives 11,500 feet for the thickness of the ice on its summit. But the mean height of the mass is certainly 500 feet less, and hence the average thickness of the ice to the north was not less than 12,000 feet; while over the plateau on the northern borders of New England it was about 6,500 feet; in the region of the White Mountains, 5,000 feet; along the seashore south of Portland, 4,100 feet, the whole height there being of ice; at the terminal cliffs, 500 feet above the sea level, with the under surface of the glacier resting on the sea bottom.

It should be here stated that the accumulation of ice to the height mentioned on the Canada watershed supposes that there was no movement northward toward or over Hudson Bay. If there were such a movement, the region of greatest height might have been to the southward of the watershed (the freest discharge being still to the south) over the St. Lawrence valley. But as already mentioned, the scratches over the region from western New York and Lake Huron to eastern Canada and Maine point toward the watershed as the head of the flow; and hence, there was apparently no discharge northward into Hudson Bay, and moreover the ice must have stood high above this region of depression. It is possible that the greatest height of the glacier was a little to the north of the summit of the watershed; but more probable that the small advantage which the region of the watershed had from its elevation, and from its contrast in this respect with the Hudson Bay depression, was retained throughout.

Now while the thickness of the ice thus increased to the northward and northwestward, the amount of precipitated moisture must have decreased in that direction. The rates of precipitation for different latitudes going northward was probably nearly the same as now in our *winters*. In summer the greatest amount of precipitation in New England occurs over the higher lands of its northern half, and the amount over Canada is but a fifth less. But in winter the region of greatest precipitation is within 30 to 50 miles of the coast. Moreover, the amount decreases rapidly in going northward or northwestward, the ratio for (1) the coast region of New England, (2) northern New England, and (3) the main part of the St. Lawrence valley with the Canada watershed, being 4 : 3 : 2.* Thus the low coast slopes take the moisture in winter, not the higher mountains of the interior. This accords with the general principle, that the winds lose their moisture mostly over the first cold lands they meet. Under this principle, the main divergence in the Glacial era from existing hygrometric conditions in the winter, would have been that the region of most abundant precipitation was situated a little farther south than now, and the amount of diminution—not the ratio—northward would have been greater, even if the surface increased give about 2,700 feet for the mean thickness of the ice. But the rate of precipitation over the northern border of New in elevation in going north in New England. We shall not therefore be led into any great error, if we take the ratio of precipitation during our winters as a basis for deductions respecting the Glacial era.

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* From the excellent rain charts of C. A. Schott recently published (Tables and Results of the Precipitation in Rain and Snow in the United States, collected by the Smithsonian Institution, and discussed under the direction of Joseph Henry, Secretary; No. 222 of the Smithsonian Contributions, May, 1872), we learn that in winter, over the sea-border region of New England, 30 to 50 miles wide, the amount of rain and snow is 10 inches or more, to 12 inches, two large areas of 12 inches occurring on the southern border and others along the northeastern. Over the northern border of New England the amount is with a small exception (a narrow loop running up to Montreal) less than 8. The chart contains no line north of that of the 8-inch line, and hence does not enable us to deduce the true mean for the region. Taking it at 7½ inches, and that of the sea-border region at 10, the ratio is 3 to 4; the latter would have to be 11¼ instead of 10, to give the ratio 2 to 3.

Blodget's rain charts give 5 inches as the average for a large part of the St. Lawrence valley. The amount for the Canada watershed would be the same, or less, since, as New England shows, there is no increase northward even if there is increase of elevation. The ratio used above supposes 5 inches to be the mean for the whole.

We have made the thickness of the ice in the region of the watershed 12,000 feet, and that over the northern border of New England 6,500 feet. But, following the rate of winter precipitation, 2 to 3, the latter should have been not 6,500 but 18,000 feet. The loss here indicated must have depended partly on an increased rate of flow over New England. In changing the surface slope from 10 to 24 feet a mile, the rate of flow would have been at least doubled; and this alone would have reduced the 18,000 feet to 9,000. Again, the more southern latitudes would have had a greater amount of evaporation and melting, and it is possible that thus the rest of the excess—2500 feet—was removed. If the loss from the last-mentioned source were in the Canada region *one-eighth* and in northern New England a little over a *fourth*, the above difference would have resulted. Thus the contrast in the elevation of the glacier surface over the two regions may have existed without supposing the land of the watershed above its present level.

The glacier probably extended in a southward direction at least 60 miles south of Long Island, where the depth of water is not over 250 feet; and perhaps 30 miles beyond where the depth is 600 feet, and then falls off abruptly.* The height of the upper surface of the glacier along the Connecticut valley may be thus made the subject of calculations. The line of 6,000 feet elevation (which should have run at right angles to the direction of flow, except so far as temperature was a cause of divergence) passing Mount Washington, probably crossed the Connecticut in the region of Lyme or Hanover, N. H. The distance from this region to the limit 90 miles south of Long Island is about 310 miles; whence the mean slope of the upper surface of the glacier down the Connecticut valley should have been about 19 feet a mile.

With this grade (supposing it a straight grade, which it would not have been throughout, as the flow of the general mass was southeastward) we should have for the height in the region of Northampton and Mount Tom, 4,100 feet above the sea; of Springfield, 3,800; of Hartford, 3,400; of Meriden, 3,000; of New Haven, 2,750; of central Long Island, 2,100 feet. The height of the terminal cliff 90 miles south of Long Island is here supposed to have been 200 feet.

The height of the upper surface of the ice over the central part of Connecticut probably averaged 3,250 feet, which would

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* See Author's Manual of Geology, page 441.

England being to that of Connecticut as 3 to 4, the thickness of the ice over the latter, considering this condition alone, should have been 8,700 feet instead of 2,700: there was thence a loss of more than two-thirds of all the snow, which loss we can attribute only to melting and evaporation. If the waste from this cause over the northern border of New England was *one-fourth* of the whole precipitation, that in southern Connecticut would have been over *three-fourths;* just three-fourths, if the ice-cliff were assumed to be 500 instead of 200 feet.

Whatever doubt exists with regard to the height attributed to the glacier about Mt. Washington also attaches more or less to the preceding calculations. But, to sustain our conclusion, we have now, in addition to the facts there observed, evidence that all the requisites of the Glacial era for the region from the Atlantic shoals to the Canadian watershed are satisfied by it. This is reason for believing that the error connected with the deduced height of 6,000 feet cannot be large. Moreover the Gulf Stream washes the margins of the banks in which the glacier has been supposed to have terminated, and would have determined a limit in height as well as length.

The evidence of a large amount of melting in southern New England proves that there was also much in northern, and therefore that the increase in the rate of flow of the glacier, after passing from Canada into New England, could not have been great enough to account for all the loss of thickness in the ice. If the ice lost was more than could be reasonably attributed to the temperature and rate of flow, as may have been if the slope from the Canada watershed was greater than our estimate, we should then have proof that the height of the surface of ice over the watershed was partly due to an elevation of the land.

The greater amount of precipitation over the vicinity of St. Lawrence Bay than over the watershed to the west, and also the higher latitude, account for the greater height of the ice in that region referred to on page 7.

XIII. (Evidence that this era of probably high elevation (the Glacial) was followed by one in which the land stood below its present level, is afforded by the height of sea-border terraces and beaches around New England and on the St. Lawrence, their height being nearly 50 feet on Long Island Sound, and 500 feet in the vicinity of Montreal, on the St. Lawrence; (in the height, equally, of the upper terrace-plain along the rivers and lakes; and in the additional fact, that the old alluvium beneath this plain was a direct result, as above stated, of the deposition by the rivers of material afforded by the melting glacier./ The greater height of the river and lake terraces as we go north, and also of sea beaches, indicates that the depression increased to the northward.) The special facts on this point need not be here repeated.

XIV. The sinking of the water level in the ocean over the world during the Glacial era by the loss of water to make ice cannot be estimated, because we know very little of the amount of ice. Hygrometric laws, alluded to on page 9, appear to indicate that the amount of ice did not increase to the northward over the interior of the continent. The southern line of the glacier which was near the parallel of 39° along the Ohio region must have made a very long bend northward between the meridians of 98° W. and 108° W. The marks of the incoming tide in deposits of the New Haven region, above mentioned, and in the overlying beds of the river floods that supervened, appear to show, in connection with the present height of the deposits, that during the closing part of the melting of the glacier, in the early part of the Champlain era, the water-level along the coast was not far from forty-five feet *above* the present line, *instead of below it.*

XV. There are no true *lateral* moraines of the Glacial era in New England. For the glacier was not a valley glacier, but one of continental character, although far from covering the whole continent. The ice moving over a rocky hill or ledge, where were detached blocks, and where others were becoming loosened with the passing centuries, would have gathered up the material from time to time, and afterward have dropped it at intervals, or at the final melting; and so would have made long trains of boulders, ranging over hill and valley, according to the direction of movement of the enclosing ice—sometimes narrow lines, like the famous trains in Berkshire, first made known by Dr. Stephen Reed; generally broader, less-defined bands. The unstratified drift is actually made up mainly of such trains. But, commonly, the different trains are blended together, and are traceable only with difficulty; while, at times, they make a straight line to the ledge from which they were derived. These trains are properly moraines, but they are *under-glacier moraines*, not lateral. If lateral moraines were made during the early stages of progress of the great glacier, they must have been obliterated by its later general movement and abrasion.

The valleys of New England have throughout a high terrace along their sides; but the material is very generally stratified, and therefore is the result of deposition from waters that once flooded the valleys. They are, in fact, as has been explained, the upper part of the Champlain formation. The decline of the glacier in the opening part of the Champlain era, must have offered in some places the necessary conditions for moraines; and such have been announced as occurring in the White Mountains by Dr. A. S. Packard and also by Prof. Agassiz. But for some cause—probably, (1) the melting taking place over the surface at large, instead of along the southern edge chiefly, and

(2) the diminished slope of the surface (due to the fact that the subsidence of the crust which introduced the Champlain era increased in amount to the northward), the two causes diminishing, if not stopping, over large regions, the movement of the ice—none were left over the general surface, or even along the larger valleys.

XVI. (No distinct *terminal* moraines of the Glacial era have been observed in New England. The great glacier terminated in the ocean on the east, southeast and south; and it may be added that during its decline, ~~in the Champlain era~~, the melting appears to have gone forward over too vast an extent of surface for the formation of proper terminal moraines.) Having a thickness on the border of 2,600 feet, it must have filled Long Island Sound as a consequence of its weight, even if the Sound—but 150 to 250 feet deep and 15 to 20 miles wide,—had not been partly obliterated by a change in the water-level; and thence it stretched on over the island (which is about 15 miles wide) to the ocean. If the land of Long Island were but 120 feet higher above the water-level than now, the southern coast would have been 20 miles outside of the present line; and, whether so or not, the glacier, if 2,100 feet thick over the island, probably lay on the sea bottom for ninety miles out, as already remarked. The shallowness of these waters is probably due partly to deposits from the glacier; and also that of the waters between Cape Cod and Nova Scotia, where the part of the glacier over Maine is supposed to have terminated.

The universal covering of drift over Long Island, holding great numbers of boulders from New England and New York, many of enormous size, suggests the idea of a terminal moraine deposit. But whether the drift was dropped mostly from the under side of the glacier as it melted, or from its melting southern edge, is open to question. The latter seems most probable.[*] In either case the deposition of the drift on the island was probably the work, not of the Glacial era, but of the early Champlain era or that of the melting:—certainly so, if the glacier over the island in the Glacial era had the thickness above supposed.

As already stated, whatever there may be of local moraines in the White Mountains belongs to the period of melting, and therefore to the opening part of the Champlain era.

XVII. The Champlain[†] era, as the term has been used by me, includes all the time from near the beginning of the melting of the glacier, down to that in which these old alluvial or Champlain deposits became terraced in consequence of a general rising of the land, when what I have called the Terrace or Recent epoch began. According to my view, the terraces are *not* a result of depositions *in* the Terrace era, (as is represented in the Vermont Geological Report (4to, 1861)); they are due simply to the wearing away of portions of the old Champlain alluvium (which once filled the valley across, excepting a river channel) by the river, while the elevation of the land above referred to was in progress. The depositions of the Terrace era along rivers are merely superficial over the Terrace-plains, the thickest being those of the lower flats or the great flood-ground of the streams.

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[*] The writer's investigations have not extended to Long Island. Mather in his N. Y. Geol. Report (4to, 1843) has an excellent chapter on the drift of Long Island, and the distribution of its boulders.

[†] The term *Champlain* was first applied to deposits of this era on Lake Champlain by Hitchcock in the Vermont Geological Report. "Champlain Division," had been previously used in the Final Reports of the Geological Survey of New York, by Mather and Emmons for the whole of the Lower Silurian of New York; but not by Vanuxem or Hall. Prof. Hall, in his works, has, like most others, employed the name *Lower Silurian* instead. As there is nothing in my view to be gained from

XVIII. If the above views are correct, then, as I have before announced, there was, in the Post-tertiary or Quaternary age, over the higher latitudes of North America, or large portions of them, an upward movement for the Glacial era, a downward below the present level, for the Champlain era, and an upward again for the Terrace era, with the change in each case greatest to the north—that is, to a limit north yet undetermined. But such a general system of changes does not preclude the occurrence of minor oscillations up or down, in different regions during each of these eras, or imply that such changes may not be now in progress.

NOTES TO PAGES 7 AND 11.—The fact that the glacier in the St. Lawrence valley was higher toward the Bay or above the mouth of the river, points to the conclusion that in Lower and part of Upper Canada, the scratches which have the course of the valley must have been made by a movement of the ice (of the lower part of the glacier) *up stream*, if made in the Glacial era. And none could have been made at any time by a movement *down stream*, unless, owing to an unequal rate of melting (in the opening of the Champlain era), the height of the glacier became the greatest up stream, so that the slope of the upper surface was down stream.

2. The following is a point of interest, although we can treat it only with indefinite suppositions.—If the thickness of the glacier over the New England border was, as has been deduced, 6500 feet (the height of the upper surface being 8000 feet above the sea level), and the precipitation equal to producing 36 inches in thickness in a year, supposing no loss it would take 2,170 years for the 6,500 feet of ice to have accumulated. A loss of one-half by evaporation would have doubled the length of time; of nine-tenths, would have made it 21,700 years. There would also have been a loss, after a while, from the flow of the glacier; but if the flow was only one foot a week (the estimate on page 199), this cause would have taken off less than a twelfth of the annual addition of 36 inches.

restoring to the Lower Silurian the term Champlain, and no likelihood that it will ever be so restored, this term is here retained for a division of the Post-tertiary or Quaternary.

Again, the thickness of 6500 feet being acquired, the precipitation would have continued, though probably with some diminution —a diminution that had been gradually introduced. Taking the amount at 24 inches, and the loss from the movement of the glacier two to two and a half inches, there would have been required a further loss of about nine-tenths of the whole by evaporation and melting to have kept the top of the glacier at a nearly uniform level. The amount of loss from evaporation and melting was undoubtedly far greater than has been estimated on page 10; for that from evaporation is large even in the Arctic; and both sources of waste may in some years have carried off all the snows that fell. But did this waste ordinarily amount on the northern border of New England to nine-tenths of the whole precipitation? Or, was the rate of motion greater than one foot a week? Or, did the glacier continue to increase in thickness beyond 6,500 feet in that region? If the average thickness over the White Mountain region can be definitely *proved*, the last of these queries will have been answered (as is obvious from page 8), and the doubts would be confined to the other two suppositions. If observations in the Arctic shall furnish something definite as to the probable loss by evaporation, this would still further diminish the doubts.

It may be that the diminution in the rate of precipitation consequent on the extension of the glacier southward (on the principle mentioned on page 206) was the chief means in fixing an ultimate limit to the thickness of the glacier.

On Trains of boulders, and on the transport of boulders to a level above that of their source; by Dr. STEPHEN REED, of Pittsfield, Mass.—I have called attention frequently, in various ways, to trains of boulders extending from a hill in Canaan, Columbia Co., N. Y., across Richmond, Lenox and Lee, Mass.* Two of these trains are very distinctly marked—the north one emphatically so. They have been often visited by geologists, and several theories published. I have been aware, for several years, that a train some two miles south of these was well marked for half a mile on the east side of the hill—locally called Dean's Hill—between Canaan and Richmond; but a convenient time to trace it to its source was not found until the last season.

Leaving the cars—Boston and Albany—at "Edwards" station, and passing up the valley leading to New Lebanon Springs, I found, a little north of the Baptist chapel, a few well marked blocks. I took their back track to the hill west of the valley and soon found a very limited outcrop of the rock in question. I passed on at the foot of the hill, through an open field, perhaps eighty rods, without seeing a specimen, then found another line of blocks. I followed this into the woods and soon found another outcropping. Both of these were small in extent, situated low on the slope of the hill, and had sent but few blocks across the valley to the eastern hill. Continuing northward, a half mile of rough walking placed me in a wilderness of boulders, generally from five to twenty feet in diameter, some much larger. No outcropping rock was in sight. The boulders extended, as far as the woods would permit me to see, east and west. Following my army of venerable guides, I went west nearly to the top of the hill before any rock, *in place*, appeared. At last I stood on the bare ledge—the object of my pursuit. Although I had no doubts of success from the first, yet it was not without emotion that I followed, by the laggards they left behind, the path of these travelers across the valley and up the long ascent of the eastern hill, until they mingled with my old acquaintances on its summit. The train is generally not more than twenty rods wide, and is well marked from the Richmond valley, over the hill, across the Canaan valley and up the Canaan hill, to its source. This is somewhat less than a mile south of the outlet of "Whiting's Pond." It crosses the crest of the Richmond hill nearly west of the Richmond railroad station. The compass course is S. 35°–45° E.

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* An early account of these trains of boulders, as observed by Dr. Reed, is given in Hitchcock's Geological Report of Massachusetts, and the latest in Lyell's Antiquity of Man, chapter xviii.

I was interested to find in this train a corroboration of a statement I made some thirty years since, that the blocks were decidedly larger and more numerous on the eastern than on the western declivities of the hills. A section of forty and I think of even twenty rods, on the east side of either the Richmond or the Canaan hill, will give larger blocks and more in number than a mile of the western slope of Richmond hill.

This fact has a direct bearing on the mode of transportation, and, like another well known, viz: that the abrasion was chiefly on the north and west sides, it points to glaciers as the agent.

Another proof of the same power is found in the elevation of boulders above their source. In Canaan, Ct., near the Housatonic river, is a low ridge of a peculiar rock, a mixture of lime, quartz and tremolite—masses of which have been carried to the Goshen hills, and scattered widely over that town. I measured a block forty feet in length and almost that in breadth, and ten or twelve high, lying on some of the highest land in Goshen, Ivy mountain excepted, and I am told there are others much larger. In the early period of this town's history it is said that a limekiln was built near one of these boulders of Canaan rock, and from it the inhabitants supplied themselves with lime for several years, leaving a huge rock which yet remains. Now these blocks lie many hundred—I think a thousand—feet above any part of the ridge which gave them birth. This is a common feature in these regions of drift action. Water, unconfined, does not carry its burden much above its own level, while glacier ice does.

[These very important facts respecting the ascent of boulders up high hills by the help of the glacier are of the same kind with others on Mt. Katahdin in Maine, where, according to different observers, boulders of fossiliferous Devonian rocks occur over the upper slopes. Mr. J. DeLaski states (this Journ., III, iii, 27) that these fossils occur at a height of 4385 feet above the sea (which is within a thousand feet of the summit) on the south side of this isolated mountain, and 3,000 feet above the low region—fifteen to thirty-five miles distant to the north—from which the fossils were derived. J. D. D.]

1875

[FROM THE AMERICAN JOURNAL OF SCIENCE AND ARTS, VOL. X, SEPT., 1875.]

ON SOUTHERN NEW ENGLAND DURING THE MELTING OF THE GREAT GLACIER.

BY JAMES D. DANA.

No. I.

GLACIAL scratches, southeastward in direction,* on the Taconic summit, Mt. Everett, in the southwest corner of Massachusetts, at a height of 2,600 feet above the sea, afford evidence that the ice which covered New England in the Glacial period overtopped this mountain, and had an elevation in that region not much under 3,000 feet. Similar facts in the White Mountains place the height there at not less than 5,800 feet.† Calculating the slope of the upper surface of the glacier over New England from these data, it follows that the height above the region of New Haven, in Southern Connecticut, may have exceeded 2000 feet, and could hardly have been less than 1500. With such facts in view, we may have some appreciation of the amount of material that was at hand, when the melting-time began, for making or deepening under-glacier streams and lakes, and, at last, swelling the waters to universal floods. The sinking of the land that took place after the ice had reached its height—placing the site of Montreal 500 feet below the sea level, making Lake Champlain an arm of the great St. Lawrence Gulf, and carrying other high-latitude lands much below their present level, a movement favoring greatly the wide extension of the floods—presents a reason for the continental change of climate which began the thinning of the glacier and finally hurried on its dissolution. The Champlain or Fluvial period—the period of this low level of the land, or the middle Quaternary—comprises, first, an era well called the *diluvial*, or that of the melting glacier and of the tumultuous floods thus occasioned, and, secondly, the *alluvial*, characterized by more quiet fluvial action. The following observations relate more especially to the earlier of these divisions of the period.

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* Hitchcock gives the direction S. 18° E. The author observed S. 27° E.

† Prof. C H. Hitchcock has informed the writer in a letter dated Aug. 13, of the current year, that he has found true transported bowlders on the very summit of Mount Washington; and this may authorize a higher estimate.

Three prominent facts appear to be established by the Champlain deposits of Southern New England.

1. The occurrence of a vast flood during the closing part of the melting of the glacier, in which other parts of New England participated.
2. The absence of marine life from Long Island Sound through the Glacial period and the early part of the Champlain period.
3. A participation in the subsidence which affected the regions farther north.

I. THE FLOOD FROM THE MELTING GLACIER.

1. NEW HAVEN REGION.

Facts proving that a great flood closed the era of melting were brought out by me in my memoir on New Haven Geology, published, in 1870, in the Transactions of the Connecticut Academy of Sciences. Since that paper appeared I have made various additional observations which I think demonstrate its occurrence still more positively, and afford also, some idea of its extent and violence.

In order that the facts may be better appreciated, a map of the New Haven region is here introduced. The region properly includes the country about the New Haven harbor or bay having the eastern slope of the high land of Orange and Woodbridge (100 to 400 feet above the sea) on the *west*, the Mt. Carmel range, nine miles from the city of New Haven, on the *north*, and the hills of East Haven, east of the bay and of the valley of the Quinnipiac, on the *east*. The rocks of Orange and Woodbridge, adjoining the region, are, like those farther west, metamorphic, being chlorite slate and chloritic hydromica slate; while those underlying the rest of the surface, beneath the Quaternary, are Triassic (or Triassico-Jurassic) red sandstone and conglomerate, with intersecting ridges of trap. The trap ridges include the West Rock Ridge, commencing on the south at W, West Rock proper; P, or Pine Rock; M Wh, or Mill Rock ridge, having Whitney peak as its highest point; E, East Rock; Mt. Carmel to the north; Rt, Rabbit or Peter's Rock; and Saltonstall ridge, just west of Saltonstall Lake. The other hills to the eastward, with a few exceptions, are sandstone hills, or sandstone and trap, with a surface of drift; and between these hills south of Mill, Pine and West Rocks, extends the broad and nearly level New Haven plain, a region of stratified drift. The principal rivers, it will be observed, are three: (1) the Quinnipiac on the east, the largest; (2) Mill River, or the central; and (3) West River, on the west, with Wilmot Brook as a prominent tributary. The Quinnipiac has very broad flats on either side, as the map indicates; and, for the most part, they are not above high tide level all the way to North Haven, six miles north of New Haven. Mill River has a rapid descent from Mt. Carmel to Whitneyville (V, within a mile and a half of the city), and West River is of similar character down to Westville. The long lake above Whitneyville (V), has been made by a dam, 40 feet high, at V. Saltonstall Lake on the east, occupies a natural depression. Height above mean high tide of West Rock at W, 405 feet; of East Rock, 360; of Mt. Carmel, 736; of Rabbit Rock, 373.

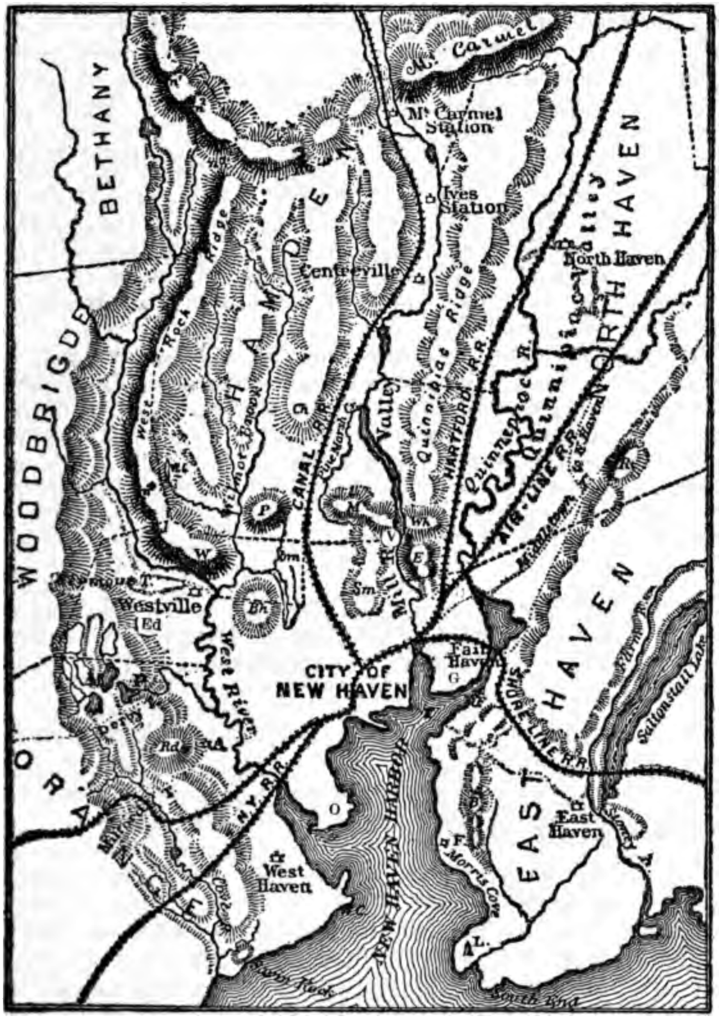
The evidence afforded by the deposits of the New Haven region is of three kinds.

1. *Structural:* the flow, when it set in, having made its mark in some places on the structure of the beds it deposited.
2. *Lithological:* the flood, where the current was strongest, having made gravel and cobble-stone deposits as a topping over the finer beds before laid down.
3. *Denudational:* the flood having produced a large amount of denudation throughout the drift formation.

1. *Structural evidence as to the flood.*—The Quaternary deposits about New Haven bay underlying the New Haven plain are estuary deposits of *stratified drift*. The average height of the upper half of the plain above mean high water level is about 42 feet; from this, there is a slope seaward of 8 to 10 feet a mile. The deposits consist of (1) sand; (2) sand and gravel; (3) rarely, of laminated clay; and in some large regions (4) layers of coarse pebbles and cobble stones.

Over the hills that rise above the level of the plain there is only *unstratified* drift, except along the small water courses.

MAP OF THE NEW HAVEN REGION.



Explanations of the Map.—A, Allingtown village. B Beacon Hill. Bh, Beaver hills. Ch, Cherry Hill. E, East Rock ridge, consisting or East Rock proper to the northwest, Indian Head next to the south, and then Snake Rock. Ed, Edgewood, the estate of Donald G. Mitchell. F, Fort Hale. *F*, Ferry Point, or Red Rock, on the Quinnipiac. J, Judges' Cave, on the West Rock ridge. L, Light House. M, Mill Rock. M P, Maltby Park, three of the proposed lakes of which are constructed. O, Oyster Point. P, Pine Rock. Rd. Round Hill. Rt, Rabbit or Peter's Rock. Sm, Sachem's ridge. T, Turnpike; also Tomlinson's bridge, across the head of New Haven bay. V, Whitneyville. W, West Rock, the south end of West Rock ridge. W C, West Cape, or West Haven Point. Wh, Whitney Peak. W. L, Wintergreen Lake, just north of Wintergreen Falls. Wn, Warner's Rock. *bm*, Beaver Pond Meadows; *m*. Mineral Spring, southeast of North Haven; *n*1, *n*2, *n*3, *n*4, different notches in the West Rock ridge; *n*1, *n*2, the Upper and Lower Bethany Notches; *n*3, the Hamden Notch; *n*4, the Wintergreen Notch.

Scale 4-10ths of an inch to the mile.

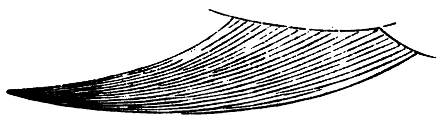
This unstratified drift consists of sand and gravel, with numerous scratched bowlders, without any underlying bowlder clay.

Large bowlders are rarely met with in the stratified drift except near the rocky bottom on which it rests. The Triassic sandstone underlying the New Haven plain in some places approaches within a few yards of the surface of the plain; and when so, the opening of trenches for sewers or other purposes brings to light a layer of gravel resting on the sandstone, which is full of large scratched bowlders, many over a cubic foot in size, and occasionally one over five hundred cubic feet. In the regions of unstratified drift, that is, above the level of the plain, bowlders are many and large, especially along the western margin of the region; and several of trap, are between 500 and 1000 tons in weight.

These facts teach, as I have elsewhere remarked, that, in the melting of the glacier and the accompanying dropping of the earth and stones, the part of the material which fell over the dry land went down *unstratified;* and that which fell into the waters was *stratified*, excepting a bottom portion made of the earth, gravel and great stones that were the first to drop from the ice. There is no evidence that the stratified drift of the plain is newer than the main part of the unstratified drift over the hills.

The stratification of the stratified drift is in almost all parts, except where too coarsely stony for it, of the *flow-and-plunge* style, as represented in the cuts on pages 173, 174. One of the parts of a layer having this structure is represented of the more common form, in the annexed cut, (fig. 1.) The oblique lamination indicates a violent onward movement in the waters; and the division of the layers into parts proves that there was a heavy plunging in connection with the rapid flow. A single obliquely laminated layer is often one to two feet in thickness, and in one case observed it was eight feet; and each must have been formed at a single onward movement of the plunging waters. This structure of the stratified drift hence shows that water and earth were let loose at the time in immense quantities; that there was a free flow of both which could have been well produced through the melting and discharge of a vast glacier; and that, consequently there was a very rapid piling up of the layers of gravel and sand.

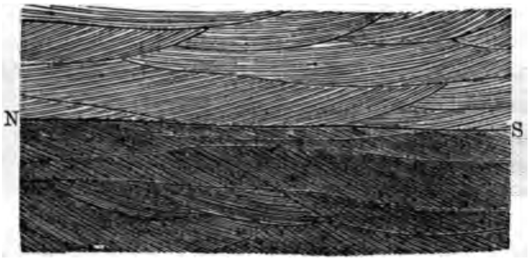
1.



In this oblique lamination which characterizes the deposits of the plain, the little laminæ rise, with only an occasional exception, *to the northward;* that is, dip to the southward, and hence prove that, throughout the New Haven estuary—then six miles in depth if we reckon only to Pine and Mill Rocks, and over half that in width and opening (as now) to the southward—the deposition took place under the pushing and plunging action of the *incoming* tide, the tidal waters having been forced into heavier plunging than usual owing to the violent resisting flood of fresh waters in front.

This rise to the northward in the oblique lamination (or dip to the southward) prevails except at the mouths of the valleys. The beds at the lower extremity of the Quinnipiac valley, just southeast of East Rock (E), afford one of these exceptions. At this place, along the cut of the Air-Line railroad between Mill River and the Quinnipiac, the stratified drift-deposits, which here have their full height or 42 feet above high tide level, are exposed to view to a depth of about 25 feet. Through the northeast half of the cut (near C) where it is within the range of the Quinnipiac valley, the beds of the upper 20 feet have the oblique lamination *rising to the southward*, that is, in a direction the opposite to that in the underlying beds, and the opposite to that which characterizes the whole thickness of the deposit over the New Haven region except at the mouths of the valleys. The following cut represents a part, six feet in height, of a vertical section, and shows the plane of junction NS between the upper and lower portions; above NS oblique lamination rises *to the southward*, and below NS *to the northward*. In addition to this difference of direction, the beds below are brownish-red, and those above rusty brownish-yellow.

2.

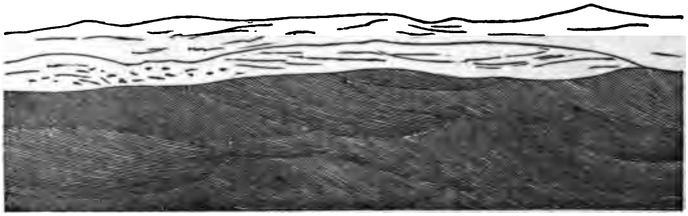


The deposits present this difference above and below for half a mile along the cut. But passing beyond this westward, or toward Mill River, out of the Quinnipiac Valley, the upper stratum gradually loses its distinctive character and becomes like that of the plain deposits elsewhere. This change on passing out of the range of the Quinnipiac proves that the existence of such an upper stratum was dependent on the flow of the river and not on any variation in level or depth, or on any subsequent action of currents. The drift deposits have a uniform level at top quite to the Mill River channel, and were all one in simultaneous origin.

Now the flow of the Quinnipiac waters must have undergone some change before the last twenty feet of sand and gravel were laid down, and it must have been a change in volume and violence. Owing to this change the current in the river became so powerful as to overcome the action of the incoming tide and take charge itself of the deposition of the earth and gravel. In other words, an extraordinary flood set in, extraordinary even at a time when a violent flood had been already long in progress; and the flood waters did the deposition even in the face of the tide.

Similar evidence of the flood should exist in the other valleys of the region. I have observed it in the valley of Wilmot Brook, near the southeast angle of West Rock (W on the map). The oblique lamination of the upper layer at the place rises to the northward, or dips southward, as at the termination of the Quinnipiac valley, and thus the place bears its testimony to the flood. The same evidence was found nearly a mile higher up the Wilmot Brook valley, where the road turns, at Selden's, to go to Wintergreen Falls and Lake, and the annexed cut represents a portion of the section.

3.



Section of stratified Drift up Wilmot Brook.

Owing to there being no good sections of the stratified drift at the extremities of the Mill River and West River valleys, I have not obtained any facts from these points.

2. *Evidence as to the flood in gravelly and stony formations.*—The material of the stratified drift-formation over a large part of the New Haven region is sand, with only small pebbles where any occur. But adjoining the river courses through the plain, especially Mill River and West River, it consists to a great extent of large pebbles or stones, and much of it of cobble-stones, many of which are six to eight inches in diameter.

The Quinnipiac Valley deposits are an exception, because the wide valley was at the time an interior harbor nearly four miles long and a mile in average width, with North Haven at its head, and much of it was over 50 feet deep. It was hence a level surface feeling the tides in their full force to its northern limit. Hence the flow of the waters through it would not have been turbulent like that along the streams of rapid descent. That this was the condition of the region is proved by the fact that the region is now one of wet peat meadows flooded at high tides. Further, the height of the stratified drift at North Haven, and at a point four miles below (near E) is alike, being not over 45 feet above the level of the flats.

The West River region shows its stony character strikingly at Westville where it leaves its narrow valley. The stony beds of the deposits follow the course of the stream southward through the New Haven plain either side of the river flats; but the stones diminish in size, at first rapidly, and then gradually, and two miles down the stream there are only pebbly beds with sand; thus showing the slower flow through the estuary of the era.

The stony beds along the course of Mill River are much more remarkable than those of West River, both in extent and coarseness. The area they occupy south of Whitneyville rapidly widens southward, becoming one-quarter to half a mile broad. The coarser part is situated to the east of the present channel of the river; and it extends southward, with a straight course to the head of the bay (south of VEN in the map), where it passes beneath the water to a distance yet undetermined. The beds consist partly of cobble stones 6 to 10 inches in diameter. The coarseness diminishes both to the east and west. On the east side of the river at the State street bridge (which on the map is near M in Mill River), where the stony stratum is 20 feet thick, the stones and pebbles are much smaller in average size than on the west side, and they diminish on going farther eastward.

Since such stony regions indicate where the waters run most violently along their valleys or through the estuary, it is evident that the main flow of Mill River from East Rock (E) southward was to the east of the course it now follows;* and up the same channel moved the great central tidal flow of the harbor. The rushing waters, combining the flow of the river with that of the ebbing tide, carried the finer material down stream, leaving the stones behind; and this finer material was made to contribute to the sandy stratified drift-deposits along the west side of the bay (where the inflowing tide now makes its chief depositions of sand), as well as to the Sound.

Now these stony beds testify to the flood not only by their presence, but more especially by their *belonging mainly to the*

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* Just south of the Shore-Line railroad, the coarse beds are wanting for nearly a third of a mile west of Mill River, or to Franklin st., as I learn from Mr. P. Chatfield.

upper fifteen or twenty feet of the formation, and therefore by their being the last work of the melting and discharging glacier. A coarse stony stratum above and fine below is found through all the Mill River stony region.* Along the sections made through the New Haven plain to the level of the river flats in grading the streets, the lower part of the exposed section is mainly of sand, while the upper is gravel and stones. The same has also been found to be true in the excavations for sewers in that part of the New Haven region. At one of these (at the corner of Orange and Laurel streets), the stony stratum was 12 to 15 feet thick, and below it the beds were mostly fine sand, the lower stony layer resting on a bed of fine quicksand. The vicinity of West River presents similar facts.

Such a transition in the drift deposits from the production of sand beds with but little fine gravel to that of beds of coarse gravel and large stones—partly cobble stones—proves that there was an equivalent change in the flow of the waters. These waters were in rapid plunging flow when the lower stratum was deposited; for the beds are characterized everywhere by the flow-and-plunge structure, and a foot is a common thickness for the bed made by a single plunge. But, however great the previous violence there was an increase afterward to a vaster flood.

The partial decline of the flood is also marked in some portions of the deposits by the return to sandy beds in the top portion attending a narrowing of the stony region. On the western margin of the Mill River stony area, in Grove street above its intersection with Church, the stony beds reach the surface for 200 feet above Church street; but from that point westward, the stony portion thins, and in place of its upper beds there are sandy and fine pebbly beds; in 200 feet this upper sandy part has become six feet thick: indicating thus the narrowing of the more violent part of the Mill River flood, as its season passed, or the melting of the glacier became completed.

In the region of the Quinnipiac valley, three to six miles north of New Haven, on both the east and west sides of the present lower flats, there are beds of fine clay, from a few feet to thirty-five or more in thickness. The upper surface is but little, if at all, above high tide level. As this Quinnipiac region was then (in the Champlain period) a great interior harbor or arm of the bay, over fifty feet in depth, still water would have existed on one or both sides of the main flow; and these clay beds, all finely laminated, indicate the positions of such still-water areas. The clay beds, when followed a few scores of yards to one side or the other, sometimes become sand beds—as at Quinnipiac, half way to North Haven; and this is demonstration that their existence depends not on the kind of deposits there let fall by the glacier, but on the quiet condition of the waters. There is also proof at Quinnipiac, as brought to my attention by Mr. S. P. Crafts, that the depositions took place before the ice had all melted; for a large bowlder—four feet in diameter—has been taken out of the clay from a depth of six feet, and some intercalations of gravel seem to have had a similar origin. At the same place, fifty feet to the west of the clay pit, a very coarse, stony stratum of stratified drift overlies the clayey stratum; the fact that the latter exists below the stony beds having been ascertained by Mr. Crafts by means of a drill, which descended through and brought up some of the underlying clay. This overlying stony bed was made by violent currents that succeeded to the still waters of the place, and these violently flowing waters were probably those of the great flood.

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* When my Memoir on the New Haven region was written I had not recognized the distinction between the upper stratum and the beds below.

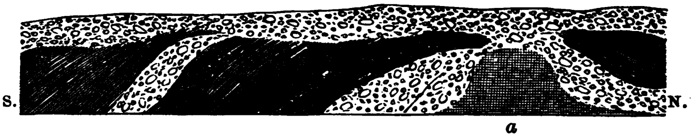
3. *Evidence as to the flood in its denudation of the stratified drift deposits.*—Along the *west* side of Mill River, where the beds are stony and of the coarsest kind, the plain is 10 feet below the usual level, the height not exceeding 30 feet above the river flats: while on the west side of the river near the State street bridge, where the stony beds are less coarse, the height is 40 to 42 feet—the full height of the New Haven plain in that latitude. The lower level on the west side continues south to the harbor, the surface sloping in that direction. The deposits of stones must have been made largely by the washing away of the finer material from the coarse—a denuding process; and it is reasonable to suppose that the lower level along the west side of the broad Mill River region was thus produced. But the river did not act alone in this; for the river-channel was also, as stated above, one of the sweeping grounds of the tidal waves and currents. Hence it is that this region of low level slopes and widens much southward, extending over half the width of Grape Vine Point (G, between the mouths of Mill River and the Quinnipiac), where the height is reduced to 10–20 feet.

The upper surface of the Terrace plain, near the junction of the Air Line and Hartford railroads, bears evidence of erosion to a yard or so in depth, over large areas of its surface, and of a subsequent deposition of fine sand.

At Quinnipiac the upper surface of the clay bed, alluded to above, has depressions that are results of erosion, and probably the eroding waters were those of the flood that deposited the overlying gravel bed.

A remarkable example of erosion of the drift deposits by the rushing waters of the flood was exposed to view in [illegible] on Blake street, directly south of the extremity of [illegible] Brook valley, (on the map between Bl and West River). The d ing cut exhibits at *a* a portion of the previous deposit of fine sand, projecting up and enveloped in the coarse gravel that the tearing waters were bearing along down stream.

4.



Section of stratified Drift on Blake St.

Various depressions over the New Haven plain may be owing to the action of the flood, which cannot now be distinguished from those due to later denudation. But there are some isolated depressions 20 to 25 feet in depth, and one, Beaver Pond Meadows, having an area of an eighth of a square mile which have no such origin. These appear to be mainly due to the deeply excavating action of the ploughing glacier, they having been parts of underglacial water-courses in the Glacial period; they were excavated to so great a depth that the drift dumped into them by the melting glacier, or carried in by its waters, was not sufficient to fill them, while other shallower areas were built on up to the water's level of the era.

Thus the great flood left its mark not only in the structure and degree of coarseness of the deposits along the water-courses, but also in denudations of the drift-covered surface.

It is to be noted (1) that the upper stony stratum is not found over all the stratified drift of a valley; for through much the larger part of the New Haven region the upper stratum is sand. Such stony beds are to be looked for only where the flood waters ran most swiftly, while beds of fine pebbles, sand or earth exist where they were less rapid, and others of clay where the movement was slight or almost null.

It is to be noted, secondly, that the coarsest stony beds do not always or generally cap the highest terrace; for the fiercely-flowing waters often denuded the surface deeply and left the larger stones at one or more lower levels—levels that are now the upper portion of one or more of the lower terraces; but which, in the era of the flood, were either under-water flats, or else the broad bed of the flooded stream.

If the stony strata may have been merely the stony beds of streams, like the stony bed of any rapid stream in modern time, it may be questioned whether they afford evidence of a flood from the melting glacier. But such a stratum is common also at the top of the upper terraces, where it could have been made only by such a flood. Both Mill River and West River valleys afford examples of this. Again, since the Champlain deposits that lie *beneath the stony beds* are made of fine material, there is full evidence, whether the latter were formed over the bed of a stream or at higher levels, that an era of comparatively quiet work was in each case *followed* by one of coarse stony depositions, and hence that there must have been an increase in the flow at the last. The Glacial period scooped out the valleys and deepened them, and then came the filling from the unlading glacier; after the bottom had received part of the large bowlders that fell from the ice, there followed the deposition of sand and finer gravel, with clays in some places, and occasional bowlders; then, finally, the upper coarse beds were formed wherever the waters at the flood could carry off the finer material or carry in coarse.

The beds of gravel and cobble stones along Mill River extend for more than two miles through the New Haven plain, or what was then the great estuary, where there was no cause for rapid flow in the stream apart from a flood of enormous extent sweeping down the valleys.

Depositions subsequent to the flood.—It may be questioned whether the flood-made upper stratum in the vicinity of the river courses, which has been above described, may not have been deposited during some flood, or era of glacier melting, later than that of the early Champlain period closing the era of the great glacier. The evidence against such a supposition in the localities which I have examined is decisive. For, as I have shown, this upper stratum when followed laterally away from the river courses, changes into the ordinary stratified drift; or, in other words, the very same stratum bears the flood-marks near the river courses, and not so, or only sparingly, over other regions. The stratified drift of the New Haven region is evidently all one formation; it is one in structure, even to its top layer. All of later origin ordinarily overlying it is about a foot or less of blackish soil; and this is simply a portion of its surface sands modified by the growth of vegetation.

There are some portions where its upper surface was irregularly eroded, as has been explained, and there the surface was later built up to the old level by depositions of fine material, easily distinguished in kind from those below, indicative of changed conditions—but only a change from the flood condition to that of the more quiet subsequent part of the Champlain period. The terrace plain near the junction of the Air Line and Hartford railroads has been mentioned as one locality of this. The sands of the later deposit are here whitish, showing that they had been washed of their iron rust. A stratified bank of the same sands exists at the northeast end of the same railroad cut (that of the Air Line railroad). The stratified drift formation here drops suddenly in height, from the 42 feet above high tide level usual there, nearly to the low level of the broad lower flats of the Quinnipiac. The slope thus made was, in the Champlain period, the northward limit of the sand-flat which constituted the south boundary of the great inner harbor. Against this slope, spreading northward, there is situated a horizontally stratified deposit of fine white sand; which evidently owed its origin to the beating of the harbor waves against the sand-flat during the quiet half of the Champlain period, that is, after the ice and the flood had disappeared. Its stratification and its relation in position to the true stratified drift is shown in fig. 5, in which ACD is the stratified drift, made up of fine sand beds (M) and pebbly beds, some of them coarse pebbly drift, and AEF the subsequent deposit of white or sea-washed sand. The sands of the latter differ from those of the other beds not only in their white color, but also in their greater fineness, and in the absence of all pebbles. Through the washing of the waters against the shores, the sands were not only ground up, but they also lost almost entirely the oxyd of iron that tinges the quartz grains of the stratified drift. Near B, at the foot of the slope ABC, there is a heap of pebbles or stones and reddish sand, which evidently fell down the bank from the layers above when it existed as an exposed slope before the beds of whitish sands were deposited. These whitish sands, moreover, were laid down in even layers, free from the oblique lamination that occurs in the stratified drift. Thus we have evidence of some changes during the Champlain period after the drift was deposited; the wonder is that there is so little of such evidence.

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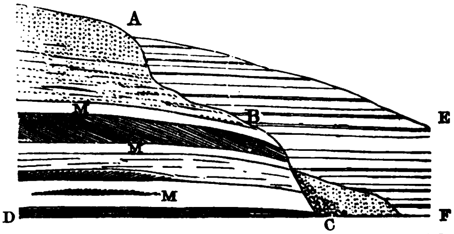

Section of stratified drift and later unconformable Champlain deposit, Air Line Railroad cut.

2. OUTSIDE OF THE NEW HAVEN REGION.

Evidence of the great flood produced by the melting of the glaciers is found along all of the rivers of Connecticut upon which I have had an opportunity for making observations.

Such opportunities are not often to be met with, since it requires an exposed section of the stratified drift of a valley—and one recently exposed, since the surface soon becomes concealed by slides down the slope. Moreover, in the narrower valleys of rather rapid descent, the waters were so tumultuous at all times that stony beds were thrown in at all levels. Ten miles west of New Haven, in the upper terrace of the Housatonic river, 90 feet in height above the flood level in the river, the upper stratum, for twenty to thirty feet in depth, is very coarse stony, and mostly sandy with finer stony beds below; and the top of a lower terrace is still coarser in its stones. I have observed similar facts in the Pequonnoc River valley, north of Bridgeport, Connecticut.

Again, to the east of New Haven, on the Thames at Norwich, the upper terrace, at the old cemetery, over one hundred feet above high tide, is exceedingly stony at surface. At the Navy Yard four miles above New London, on the east side of the Thames—where, as elsewhere on that side, there is only a narrow terrace on account of the crowding rocks—the following facts were presented in a cross section. The height of the terrace is about 30 feet. At a distance of 40 to 50 yards from the river there is at top a stony layer but two feet thick; and this rests on a horizontally stratified sand-bed.* Passing toward the river, the stony portion increases in extent, and also in coarseness, becoming a cobble-stone bed; and at the river, the whole of the formation, so far as in view, was of stones—that is the upper three-fourths, the lower part being concealed by the fallen gravel. Half way to the river along the section, irregular patches of sand beds, two or three yards in length were included among the irregular stony layers, after the style represented in fig. 4, (p. 178). Thus the flood-torn stony features of the formation increase toward the river; and some of the sands of the uprooted sand beds were left in patches among the stones.

To interpret the facts we have to note that the Thames is a wide and deep tidal estuary, or rather fiord, fifteen miles long; that, therefore, there is no seaward slope to make rapid currents. The earlier drift deposits, should hence have been of the finer kind, and in regular beds; only the extraordinary conditions of a glacier flood could have occasioned any other result. It must, moreover, have been a flood of enormous volume, with the violence of a cataract, to have produced, along such an estuary, so extensive erosions and cobble-stone deposits. Although I observed no other good section, I think it safe to say, judging from the stones which had fallen from some of the layers, that the formation, for at least half a dozen miles north of Groton (the part I examined), was very stony near the river, while mostly free from stones on the side toward the hills.

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* The section in this part showed only four feet of the underlying sand stratum. Fifteen yards nearer the river these four feet consisted of large stones and gravel instead of sand, being part of the stony stratum alluded to above.

On the opposite or western shore of the Thames, at Montville, six miles north of New London, where the terrace is one half higher, the facts are even better testimony to the same conclusions. The stony beds occupy a large part of the formation in a bluff close by the river between the shore and the railroad track, while forty yards farther from the river, to the west of the track, they are mostly confined to the upper third or less of the deposits. Further testimony with regard to the extent of the flood in the Thames will be given in another paper.

In a recent journey in Vermont, I found many examples of an upper stony stratum along the valleys. West of Ludlow, the upper stratum of the high terrace on the south side of the valley was coarse stony, while below the beds were mainly of sand. At Sutherland Falls, on the Otter Creek (or River, as it should be called), where fine sand was the main constituent of the formation—being fine enough for use in the marble mill—the upper portion for 8 to 20 feet was very pebbly, the pebbles mostly half to one inch in diameter. Just north of Pittsford, on the high terrace of a branch of Otter Creek, there is a coarse upper bed; and one still more coarsely stony on the terrace 50 feet or more below the highest, while the beds below were comparatively fine; also south of Rutland, in the upper part of the high eastern terrace of Otter Creek valley, especially near the junction with the valley of Cold River, and also with that of Mill River, west of the gap passed through by the railroad to Cuttingsville.

Professor Hitchcock, in his Report on the Geology of Massachusetts, makes the general statement that the material of the upper part of the terraced river formation generally differs from that below in being coarser. He refers on page 361 of his Geological Report of Massachusetts, to the fact, observed by him, that the clay stratum of stratified drift is almost always overlaid by sand, and then adds that, sometimes, toward the top, the clay is interstratified with beds of sand [evidence only that there were transitions from gentle to rapid movements in the waters] and then, above, the clay is absent, and "the sand becomes coarser, until, at the top, frequently small pebbles are found, and other evidences of agitation in the waters."

Conclusion.—If river valleys so widely apart over New England, and so many of them, bear evidence of a flood closing the existence of the glacier, we may reasonably conclude that all New England was, sooner or later as the melting progressed, swept by it. In fact, if the flood in any part was due to the rapid melting of the disappearing ice, it must have been thus universal; for the rapid melting would have been general.

The flood unquestionably preceded the ending of the ice; for, as already stated, only a melting glacier could have afforded the vast quantities of water required to fill and flood the wide valleys, and have set loose, simultaneously, the immense amount of sand, gravel, and stones, that were at the disposal of the waters.

The flood appears also to have risen rapidly to its height; for (1) the transition from the finer deposits to the upper coarser stratum is generally rather abrupt, and (2) at the lower extremity of the Quinnipiac valley, the change in the structure of the beds, from tide-made to flood-made, marked in the reversal of the oblique lamination, (page 173) took place along a well defined plane without any alternations, and was visible also in the color of the deposited sands.

Finally, the flood was a natural termination of that winter of winters: especially as the rigors of the Glacial climate had passed, and a lower level of the high-latitude lands was bringing on a time of warmer climate than the present—the era when even Britain was occupied by wild beasts of the warm temperate zone.

From what precedes it appears: 1, that the atomic weights of elements of similar properties form series, the difference between the lower terms of which series being sixteen, for the middle terms forty-four to forty-seven, and for the largest eighty-eight to ninety-six; 2, that certain terms of some of these series may be wanting.

This law, together with the law in regard to the variation of the specific gravities in the different lines of the given scheme of the elements, could be used in fixing the value of a new atomic weight after its determination by analysis. The specific gravity being known, there could be two points equally distant from the maximum or minimum in each line, in which, in general, the element could be placed; the value as found by analysis, or one of its multiples, would satisfy one of these positions.

It is somewhat strange that there is no position for hydrogen in the table.

ART. XXXVII.—*On Southern New England during the melting of the great Glacier;* by JAMES D. DANA. No. II.*

II. ABSENCE OF MARINE LIFE FROM LONG ISLAND SOUND THROUGH THE GLACIAL AND PART OF THE CHAMPLAIN PERIODS.

THE fact that the stratified estuary and seashore deposits of the New Haven region, and of other parts of the Connecticut coast bordering on the Sound, afforded me no trace of marine life was a puzzle so long as I looked upon them as true beach-made accumulations. I have continued my search at various localities, up to the present time, and in no case have I met with shells or other sea-relics. The evidence proves that the deposits are not of beach origin, but drift deposits made by the waters and gravel or sand of the melting glacier as they together hurried onward in floods to the sea, conjoined there with the action of the tidal currents and waves; and it establishes also, as I believe, that true shell-bearing sea-beaches do not here exist.

The same absence of marine products appears to characterize the drift along the northern shore of Long Island, or southern side of the Sound. The extended investigations of Professor Wm. W. Mather, while geologist of the State of New York, brought nothing of the kind to light; and my own recent examinations of the drift on the Island have been as barren of discovery. Moreover, I could gather no evidence from persons living in

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* For No. I. of this Memoir, see page 168.

In this table all of the above series are given, and the series, consisting of several members for each term, also, find their place. When we start from Be=9·4 and notice the following elements in the same line, we find that the atomic weights continually increase till Mg=24 is reached; there are no more elements in the same line, the next highest being Al(=27·4) in the second line; the case is similar for this line, the atomic weights increasing to Ca(=40), the next above being in the third line. The difference between the first and second lines is about sixteen units; it becomes forty-four plus for the second and third, and third and fourth; and is, finally, about ninety-three for the last term of the series, from Ti, Nb, Ta to Be, Al, Th. These three differences do not seem to be constant, but to increase with the values of the atomic weights; this is most apparent for the largest; the smallest appears constant.

It would seem probable that the lower terms of the series after magnesium, and as far as aluminum, should be wanting; as, otherwise, there would be two elements of equal atomic weights and differing largely in their chemical natures; which last would be shown by their having to be placed in different parts of the table, which does not occur. From Ba(=137) to the next highest, Ta(=182) is forty-five units, about the value of the middle difference. If there were other elements between these, there would be a similar anomaly to that just mentioned. The last terms of the series having the largest difference for their last terms, are Ta(=182) to Th(=231); the increase in these is forty-nine units. It may be that Th(=231) is the largest atomic weight.

One advantage of the table is its bringing elements of similar chemical and physical characters together. The metals and metalloids are separated almost completely.

There are certain objections to the classification of some of the elements in the series in which they have been placed. It appears that the chemical properties do not always exactly correspond in the members of the same series; this is best shown in the case of the soluble oxides and sulphides; others are those of thallium and lead, and perhaps silver. The boundaries in neither of these cases are to be considered sharp, and in both are oblique.

There is a singular fact in regard to the specific gravities of the elements, when thus arranged. The specific gravities of the elements in the same line vary regularly and have one maximum and minimum; the maximum is in each case in the neighborhood of the members of the gold group, and the minimum among the metalloids; the positions of these two points are farther to the right, the lower the line; this is best seen for the minimum. The numbers above the symbols give the specific weights. Uranium is an exception.

Atlantic border, if not along the southern shores of this island. Under these circumstances the old life, which might early have repeopled the southern shores of Long Island and the seas on the east, would have been slow in repossessing itself of Long Island Sound.

Although the Sound has yet afforded no evidence of molluscan life in the Champlain period, there is a deposit full of shells, according to Mr. Sanderson Smith,* on Gardiner's Island, off the east end of Long Island at the entrance to Peconic Bay.* The bed has a height of fifteen or twenty feet above the sea level. The species mentioned in the article are: *Nassa trivittata*, *N. vibex* Say, *Fusus decemcostatus ?* Say, *Purpura lapillus* Lam., *Columbella lunata* Say, *Natica duplicata* Say, *Chemnitzia interrupta* Stimp., *Crepidula unguiformis* Lam., *C. fornicata* Lam., *Bulla canaliculata* Gould, *Ostrea borealis* Lam., *Pecten Islandicus* Chemn., *P. Magellanicus* Lam., *Arca transversa* Say, *Cardita borealis* Conrad, *Astarte sulcata* Fleming, *Venus mercenaria* (very thick and heavy shells, broken but not rolled and making the bulk of the deposit), *Mactra lateralis* Say, *Mya arenaria* Linn., besides three other doubtful species.

In the above remarks I have assumed that the ice which carried the bowlders to Long Island was that of the glacier and not of detached icebergs; in other words, that the glacier did not terminate along the Connecticut shores in the early part of the Champlain era during the melting, and give off icebergs for farther southward transportation. This point, which has some arguments in its favor, I propose to consider in a future paper on the geology of Long Island. Even if the glacier had its southern limit along Southern New England, the Sound would have been filled with the floating masses, and its waters, greatly freshened by the under-glacier streams, poured in along the whole coast and by the melting of icebergs; the exclusion, therefore, of the molluscan, articulate and vertebrate life of existing species from the Connecticut coast would have been nearly or quite complete.

ART. XXXVIII.—*Corals at the Galapagos Islands*, by L. F. POURTALÈS.

THE Galapagos Islands are, as is well known, an important point in the geographical distribution of corals, being almost exactly on the boundary of the coral-producing part of the Pacific Ocean, and that portion which is destitute of them on account of the low temperature of the water. All the writers the sea-border towns that any shells had been found in the drift deposits *

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* Ann. Lyc. Nat. Hist. of New York, viii, 149, May, 1865.

Long Island Sound—the strip of water, 100 miles long and 5 to 20 miles wide, separating Long Island from Connecticut—is a very shallow trough. Its depth from its western limit to the mouth of the Connecticut river nowhere exceeds (as the Coast Survey charts show) 170 feet, and in general is between 75 and 100 feet; and through the small eastern portion, east of the Connecticut, it is for the most part under 200 feet. The depth was probably less than this in the Glacial era, since there is strong evidence that the water line was then at least 100 feet below its present level. However this be, so shallow a trough should have been occupied throughout with ice, if the glacier over Southern Connecticut were 1 500 feet in thickness, or even 1,000 feet; moreover the trough would have been the course at bottom of one of the largest of New England subglacial streams, since all the subglacial rivers passing through the State of Connecticut, including the chief river of New England, the Connecticut, would have been its tributaries. As the Champlain period opened the land subsided, giving greater depth of water to the Sound than now exists. But, with the melting going forward, the great stream of the Sound would have been swollen immensely in volume, and finally have borne icebergs seaward.

Such being the glacial conditions, the continuance of molluscan, articulate and verbetrate marine life in the Sound, like that now existing there, would have been impossible, and an extermination nearly or quite complete of the old fauna must hence have taken place.

After the melting of the glacier had ended, the return of the old species to the Sound sooner or later began; and it was probably accomplished before the Champlain period—the era of low level and great rivers—ended; but, with no elevated beaches to refer to as proof, the evidence of this fails us. The glacier had probably exterminated the temperate-climate life also of the seas just south of Long Island; for numerous bowlders, from one ton to two thousand tons in weight, of New England origin, show that the ice stretched on from the Sound in full force over Long Island, and must have had its terminal ice-cliffs somewhere to the south in the shallow water of the

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* Prof. Mather in his New York Geological Report (p. 262) gives, from the verbal reports of others, statements respecting the discovery of shells on Long Island, which are, in part at least, of uncertain credibility, and are supposed by him to indicate, where of value, the presence of Tertiary deposits or of Tertiary and upper Cretaceous, beneath the Drift. Besides the localities on Long Island, at depths varying form thirty to more than a hundred feet, shells are stated to have been obtained on Governor's Island, in New York Harbor, at a depth of about 100 feet. None of the shells or localities have ever been seen by a geologist, so that the precise value of the evidence is still in doubt.

If the exact weight of the counterpoise *kno* be represented by x, then

$$\frac{x.ab}{as}=\text{weight of mineral in air.} \qquad (1)$$

$$\text{Also } \frac{x.ap}{as}=\text{weight of mineral in water.} \qquad (2)$$

$$(1)-(2)=\frac{x.ab}{as}-\frac{x.ap}{as}=\frac{x.bp}{as}=\text{weight of water displaced.} \qquad (3)$$

$$(1)\div(3)=\frac{x.ab}{as}\div\frac{x.bp}{as}=\frac{ab}{bp}=\text{specific gravity of mineral.}$$

Hence the specific gravity is known if the ratio $\frac{ab}{bp}$ is known. This ratio is indicated upon the arm *ab* for as many points as possible.

An arm *ab* 12·6 inches long may be graduated to tenths as high as seven, while low specific gravities may be indicated with much greater exactness.

It will be seen that this balance does not determine weight, and that it renders mathematical computation unnecessary.

Worcester, Mass., Aug. 30, 1875.

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Mr. S. P. Crafts, the proprietor of a clay-pit at the village of Quinnipiac†—whose intelligent interest in the geology of the region has kept him on the lookout for fossil leaves and bones, glacial bowlders, and whatever would illustrate the origin of the deposits—has recently brought me from his pit two bones, the second within the month past. One of the bones is a humerus and the other a tibia. The humerus was taken from a depth of 11 feet in the clay bed, and the tibia, subsequently, at a depth of 7 feet. Professor Marsh has given me the following note on these bones for this place:

"The two bones from the clay pit of North Haven are the right humerus and left tibia of a species of Reindeer, about the size of *Rangifer tarandus.* The two bones did not belong to the same individual, the humerus indicating a younger and somewhat larger animal. The tibia is the more characteristic specimen, and agrees so closely with the corresponding bone of the European Reindeer (*Rangifer tarandus*) that it must have belonged to the same or a very nearly related species. Its resemblance to the tibia of the American Caribou (*Rangifer caribou*) is much less marked. The humerus also evidently belonged to a Reindeer, but the proportions are somewhat similar to those of the Caribou."

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The bones give us an insight into the life of New England in the early part of the Quaternary, proving that Reindeers of the Arctic type were living here. From the facts we gather that:—

1. The bones are probably not of pre-Glacial age. They are certainly not bones which the glacier had taken up from the soil underneath it along with moraine material for transportation and deposition: this being evinced by their freedom from all wear and fracture. The clay was produced through the glacial abrasion of hard stones; and surely if the bones had been in the same mill they would have been ground up too, or at least would have been in some parts worn or broken. It is possible that they were lying in the soil near by when the ice-period began, and that subglacial waters washed them into the basin with the depositing clay; but this is far from probable.

2. They were placed where they were found during the formation of the clay bed, and were deposited at widely different times, four feet in thickness of the clay intervening between them. They therefore belonged to different individuals.

3. The clay bed is of glacial origin. For it contains an occasional bowlder of large size,* and is overlaid by sands and gravel of the stratified drift.

4. If the reindeer bones were not pre-Glacial they must have come from reindeers living in the Quinnipiac valley after the glacier had retreated to the north of the valley. And since the clay-bed is of glacial origin, its bowlders must have come from ice-floes that floated down stream from the retreated glacier.

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In my Memoir on the Geology of the New Haven region, I referred the clay-beds to the later or "Alluvian" part of the Champlain or Fluvial period, supposing them to be the mud-deposits made along the borders of the great Quinnipiac basin or inner New Haven harbor, during the more quiet portion of that era of submergence; and the sand-beds overlying and underlying the clay beds at North Haven I referred to the same time. But the discovery since then of the large bowlders in the clay beds,* and of evidence that the deposit of coarse stratified gravel situated along side of the clay pits actually overlies the clay in places, as proved by boring, appears to force us to the conclusion that the clay beds were (1) completed after the glacier had retreated from the valley, and (2) before the final flood.

6. Whether this retreat of the glacier was a *temporary* retreat, produced by a warm interval in the era of ice, or whether it was the *final* retreat, marking the progress of its final dissolution over New England, it is not easy positively to decide. The formation of stratified drift over the New Haven region has no break in the succession of its beds to mark such a retreat and return of the ice; and the clayey stratum contains no layer of vegetable or animal debris as testimony to a warm interval. All that the few facts suggest as to climate is that it was such as reindeers liked, which means that it was cold, and that the ice was still not far off to the north.

Remains of the Reindeer have been found in Northern New York on Racket River, and in Southern, at Sing Sing; in New Jersey, at Vincentown, Burlington County; and in Kentucky at Big Bone Lick. The specimen from Vincentown described by Dr. Leidy† and that from Sing Sing, mentioned by Mr. R. Fisher‡ were antlers. Dr. Leidy says that the Vincentown "antler bears a nearer resemblance to those of the Barren Ground [or Arctic] Reindeer than it does to those of the Woodland Reindeer [or Caribou], but differs in some respects from both." In my Geological Manual I have suggested that these remains may indicate the occurrence on the American Continent of the *second* glacial era so well marked in Europe by the reindeer remains in Southern France. But they may, on the contrary, have belonged to the same time with the Reindeers of the Quinnipiac valley—the era of melting of the great glacier of the *first* glacial era.

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ON the evening of February 12th, 1875, at about half past ten o'clock, a very large meteor was seen passing from S.W. toward the N.E., over Northern Missouri and Southern Iowa, and coming to the earth in the form of a shower of stones, in Iowa County, Iowa, a few miles east of Marengo.

At this hour the sky seems to have been quite clear over the greater part of the States named; though light clouds and a sort of haze are spoken of by observers in the counties adjoining the place where the stones fell, so that the meteor was seen throughout a region extending at least 400 miles in length from S.W. to N.E., and 250 miles in breadth.

In their descriptions of the course it pursued the accounts of observers varied with their positions with reference to the place where it fell. Those east of this region thought the course to be toward the west or northwest, those north described it as moving toward the south or the southeast, and in a few cases the statements of different observers in the same town are contradictory as to the direction of its motion.

The brilliancy of its light, and the concussion which accompanied its fall, were such as to attract very general notice, considering the lateness of the hour, and we believe that the observations herewith presented will be found to determine the path it pursued with a fair degree of accuracy.

I will give, first, those descriptions which relate to its general appearance, as nearly as possible in the language of the observers

At Keokuk, Iowa, it is described as "Oblong in figure, with a train ten to twelve times the length of the body, giving an intensely brilliant light, of crystalline whiteness at the center, fire red on the border, and throwing out red sparks and purplish jets of flame; train less luminous than body, exploded like a rocket. Opinions were divided as to whether any detonation accompanied the explosion." These observations were collected for me by L. C. Ingersoll, M.D., from a number of persons in that city who witnessed the flight.

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Mr. G. Holm of *Marengo*, gives an account similar to the last, and in addition says that the descending path was *wave-like* and not a uniform curve. Mr. Frank McClintock of *West Union*, says that "at about the middle of its course it appeared to give a slight dart or bound toward the east." Probably the same wave-like motion spoken of by Mr. Holm, when viewed from a station not far removed from the direction in which the meteor was moving.

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If the exact weight of the counterpoise *kno* be represented by x, then

$$\frac{x.ab}{as} = \text{weight of mineral in air.} \qquad (1)$$

$$\text{Also } \frac{x.ap}{as} = \text{weight of mineral in water.} \qquad (2)$$

$$(1)-(2) = \frac{x.ab}{as} - \frac{x.ap}{as} = \frac{x.bp}{as} = \text{weight of water displaced.} \qquad (3)$$

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Hence the specific gravity is known if the ratio $\frac{ab}{bp}$ is known. This ratio is indicated upon the arm *ab* for as many points as possible.

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ART. LII.—*On Southern New England during the melting of the Great Glacier;* by JAMES D. DANA. No. IV.*

IV. DEPRESSION OF THE LAND, OR AMOUNT OF SUBSEQUENT ELEVATION.

THE higher of the terraces of stratified drift, especially of those along the shores of estuaries and tidal inlets, or within the lower tidal part of the river valleys, are rightly regarded as evidence, *after making the necessary deductions*, of the amount of upward change of level which the region containing them has undergone. The following are some heights above high-water or flood level observed in Southern New England:

1. The terrace plain, or upper level of the stratified drift, in the northeast corner of the New Haven plain, near Whitneyville —50 feet; and in the northwest corner, at Westville—47 feet.
2. On the Housatonic River near Birmingham, ten miles from the Sound and nine miles west of New Haven—95 feet.
3. In the Connecticut valley, in the vicinity of Middletown, about thirty miles from the Sound and twenty-three miles northeast of New Haven—150 feet.
4. At the head of the fiord called the River Thames, at Norwich, sixteen miles from the Sound and nearly fifty miles north of east of New Haven—110 feet.
5. At the head of Narragansett Bay, about Providence, a mile above the mouth of Providence River, and about 100 miles north of east of New Haven—80 feet.

Here we have terraces at five places in Southern New England, thirty miles or less from the Sound, and within reach of the tides, having the following heights above flood-level: near New Haven, 47 to 50 feet; at Birmingham, 95 feet; near Middletown, 150 feet; at Norwich, 110 feet; and at Providence, 80 feet. What are *the necessary deductions* to be made from these numbers in order to obtain for each place the amount of that change of level (the depression of the land when the deposits were made, and the subsequent elevation) which led to the present elevated position of these plains of stratified drift, making them into river-valley and estuary terraces? If any elevated shell-bearing sea-beaches existed on the shores of the Sound, the question as to the amount of elevation since the Champlain period would be easily answered. But such evidence as already explained, is wanting; and wanting also outside of the limits of the Sound, even to Cape Cod.

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* For the preceding parts of this memoir see pp. 168, 280, 353, of this volume.

In order to make correct observations on this subject and arrive at right conclusions, several points have to be noted, a brief review of which is here given by way of introduction.

1. The height to be measured should be that of the highest terrace plain above the level of the highest modern flood-plain or lower flats. For the terrace-plain, where of full height, marks approximately the flood-level of the Champlain era, just as the flood-plain of a stream in these modern times marks the level nearly of modern floods. This point has been considered in obtaining the numbers for the heights above given, each being the height of the terrace-plain above flood-water level.

2. An allowance has to be made for the excess in height of the Glacial flood—that attending the melting—over the height of modern floods. If modern floods raise a stream 20 feet above low water mark, and hence make a flood-plain at that height, and a Glacial flood were so great as to produce a rise of 50 feet above the same low-water line, the flood-plain made from the depositions of such a Glacial flood, if at the water-level, would be 30 feet higher than that from ordinary floods; and when the flood subsided, the flood-plain so made would exist as an elevated terrace, 30 feet above the lower flats, although there had been no change of level whatever. The terrace here is evidence of the height of the flood, and not of any change of level in the land. Moreover, supposing in addition, an elevation to have taken place, 30 feet of the height of the Glacial flood-plain, if of the full normal height, would have to be credited to the excess in height of the Glacial flood.

Moreover, the deposits of those thirty feet may all have been made in *shallow* water, that is, each near flood-level, as the flood rose in height; so that the marks of shallow-water origin in the lower and overlying beds would not in this case be proof of a gradual subsidence as the deposition went forward.

3. A further allowance has often to be made on account of

local obstacles to the free discharge of the waters, giving a local height to the flood, much exceeding that usual along the valley. When a river valley is suddenly contracted, or when large tributaries join it at a given point, the stream may be carried in such places to an abnormal height—and so produce deposits up to that abnormal level—because the water cannot escape as fast as it is supplied. Moreover, for the same reason, the depth of water in the receiving estuary, and in the Sound just off the mouth of the stream, are elements to be considered; since, if very shallow, the water, under a flood of supposable magnitude, might be raised in an estuary several yards above the true tide-level; and a few feet perhaps over shoals off its mouth in the Sound, notwithstanding the wide spreading of the water on either side.

4. To guard against error, the true limit between the *stratified* drift of a valley or estuary and the *unstratified* of the adjoining hills must be carefully determined, for only the former is the terrace or flood-made formation. To be sure of correctness on this point, it has to be considered that the *unstratified* drift has sometimes locally a degree of stratification of a tumultuous kind, due to the rush of waters from the melting glacier; and, again, the *stratified* drift may fail of distinct bedding. Hence in all cases a wide range of level terrace-plain—so wide that there can be no reasonable doubt that it was levelled under water, should be sought for, in order thereby to confirm the evidence from other sources as to the deposits being of under-water origin.

An important mark of such river-valley, estuary or sea-border formations consists in the total or nearly total absence of great bowlders from their level surface. The slopes of the hills above carry bowlders usually down to the level of the plain; then they cease suddenly, scarcely one existing over the plain that tops the water-made deposits. This may be observed along all the river valleys of New England, and also in many places on its shores. Between Watch Hill and Point Judith, the hills are thickly strewn with the huge blocks, down to within eleven feet of high water level; there, along a large part of that coast, wide meadows are spread out without a bowlder. But wherever the surface over the meadows swells upward above the eleven-foot level, it is peppered as thickly with bowlders as the slopes of the neighboring hills. Some bowlder-areas occur that are scarcely above it because the surface there was at the water's level when the bowlders were dropped. The ice, as melting went forward, let go first the great rocks that were in its bottom or lower part, and where there was water underneath instead of land they sunk and were spread, along with much coarse gravel, over the bottom, there to be buried beneath later depositions. The material of these later beds along the river valleys was brought down and deposited by the flooded river as the melting went forward and the glacier retreated; or they were carried into the valley from the hills either side of the valley—all the slopes under the deluge of waters sending down earth and stones, as well as the ravines and side-valleys, to be stratified and levelled off by the rushing stream.

It is not safe to infer that all New England hills with grassy bowlderless surfaces are parts of a valley terrace; for some regions afforded few bowlders to the ice; or only soft easily decomposable material; but when the hills rise to a common height and have a flat top, there can be little reason for doubt.

5. It is further to be noted that the terrace or terraces of a region may be only one or more of the *lower* terraces instead of the highest; that is, in other words, the *highest* normal to the region may be wanting, either (1) because there the flood-waters made no depositions up to flood-level, owing to its fierce rate of flow, or some other cause, but built up only to lower levels; or (2) because the highest part of the formation, after its deposition, was swept off and so reduced to a lower level by the flood when in its period of greatest violence, leaving only a lower terrace in its place, with perhaps traces of the higher, or often, not even these.

6. A careful study of the kind of *stratification* in the deposits is needed in order to determine whether the beds were deposited (1) under the action of the *incoming tide* on the sands and gravel from the dissolving glacier or drift-covered hills; or (2) under the action of the *outflowing river*. This study requires that the cuttings for all road-gradings, wells, sewers, and cellars, in the stratified drift of an estuary, should be carefully examined. When the facts as to structure are fully understood, the question whether *sea-made* or *river-made* may in this way receive a positive answer even along shores having no raised shell-bearing sea-beaches.

7. An examination should be made for stratified deposits of the *later* or "Alluvian" part of the Champlain period, and a comparison of the heights of such beds with that of the *early* Champlain beds or true "Diluvian" stratified drift; for such beds may show at what level the waters of an estuary or inlet stood after the Glacial flood had for the most part or wholly subsided.

The mere statement of these points is sufficient to evince that the problem before us—that of determining the amount of depression of Southern New England during the Champlain period, or, of elevation since then—is beset with difficulties. These difficulties I have not been able in all respects to surmount; and my present purpose is to state the facts which I have observed, and not to announce positive results. The observations needed to settle all doubtful points demand long-continued investigation in each estuary region of the coast, such a study as can be satisfactorily carried forward only by one who is living in the region and is thus always at hand to take advantage of every excavation that may be made in the deposits for cellars or other purposes. And to this should be added an accurate topographical and hydrographic survey of the estuary regions, and of the river valleys within thirty miles of the coast.

After these preliminary considerations I proceed to the discussion of the facts bearing on the level of Southern New England in the Champlain period, or, its equivalent, the amount of elevation which may be proved, from existing conditions, to have taken place since that period.

I. New Haven Region.

The evidence with regard to the amount of depression over the New Haven region which has been obtained is from the following sources:

1. From the height of the upper or highest terrace of a region above mean high tide.
2. From the depth of the valley-excavations along the rivers and estuaries, or the height of the upper terrace above the flood-plain of the present streams.
3. From the structure of the beds.
4. From the existence of "Alluvian" deposits.

1. *Height of the terrace-plain or stratified-drift formations above mean high tide.*—This terrace-plain in the New Haven region is the wide plain upon which the city is built. (The map of the region is here reproduced, in order that the relations of the localities referred to beyond may be appreciated). It extends *southward*, by the west side of the New Haven Bay, through West Haven to the Sound east of Savin Rock—a rocky point terminating the first range of hills on the west. It is also continued northward through Hamden to Mount Carmel; but it gradually diminishes in width in this direction and at last is confined to the vicinity of Mill River. The distance from Savin Rock to Mount Carmel in an air-line is eleven and a half miles, and it is one sloping plain. From the upper part of the city (about four miles north of Savin Rock), where the land is 45 to 47 feet above mean high tide, there is a gradual slope seaward (that is, southward), toward the West Haven coast, of 10 to 11 feet a mile; and there is also the same gradual rise northward toward Mount Carmel. No trace of any beach-like break is to be found across the surface; no line of sand hills or ridges; nothing whatever to make one part more than another to look like the course of a beach or water-line.

This is well seen, for the lower part of the plain, when standing on a bridge in the West River valley: an unbroken terrace makes the sides of the river valley from Westville, where the height is 47 feet above mean high tide, to the mouth of the stream, where, opposite Oyster Point, it is 20 feet; and going on toward the West Haven beach, the plain continues its slope, terminating with a height of 5 feet at the beach, or 8 feet just back near the western hills. And for the middle and upper part of the plain it is apparent along the road (Dixwell avenue) passing over the great plain from New Haven northward into Hamden, where the surface over a very wide area is all open to view so that any abrupt change of level or variation in the surface would be easily detected if such existed. There are hence on the surface of the plain no marks of a shore-line of the Champlain period.

Again, no sea-shore or beach deposit is found anywhere about the lower slopes of the hills above the level of the plain. The passage is every where abrupt from the even plain to the rising hill-side, that is, from the terrace of stratified drift to the unstratified drift of higher levels, and this is true quite to Savin Rock on the Sound. On the east side of this bay the same is true; but the terrace on that side is mostly wanting, and the cape is rocky, so that the fact is less significant.

The following are the elevations of the plain at different points between the Sound and Mt. Carmel village.

			Feet.
Near Savin Rock beach, on the Sound,			5
0·5	mile north of Sound,	highest near foot of hills,	10–14
1·5	miles “ “	S.W. of bridge over West R.,	18
2	“ “ “	c. Kimberly and Greenwich sts.,	23
2·5	“ “ “	on Putnam st.,	31
2·9	“ “ “	c. of Congress av. and Cedar st.,	35
3·5	“ “ “	c. of Elm and York sts.,	42
4	“ “ “	c. of Dixwell av. and Henry st.,	49
4·5	“ “ “	c. of Dixwell av. and Division st.,	52
5·3	“ “ “	c. of Dixwell av. and Dudley st.,	61
6	“ “ “	Dixwell, near house of H. Munson,	68
6·5	“ “ “	Hamden church on Dixwell av.,	76
7·25	“ “ “	Dixwell av., near J. E. Bassett's,	82
9·5	“ “ “	N. Centreville, at meeting of roads,	103
11·5	“ “ “	near Mt. Carmel village,	115

An even slope is not to be expected since (1) the shore flats or flood-grounds of a river or lake are never even; and because (2) terraces have often lost much of their height by denudation, or gained or lost in height through drifting sands.*

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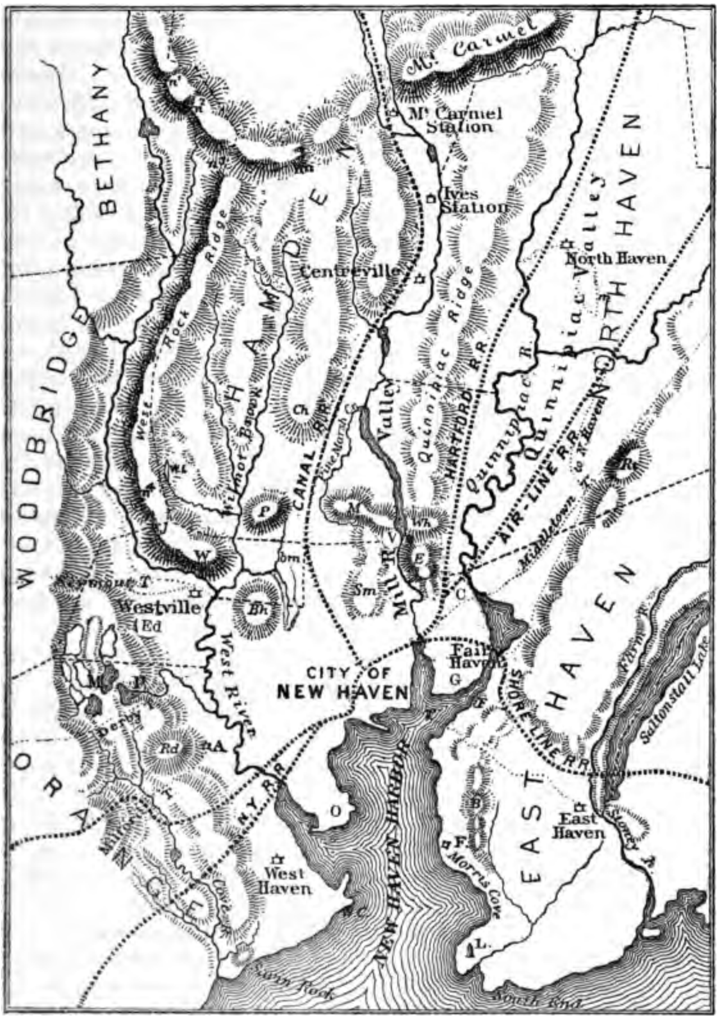
* I am indebted to Mr. C. E. Fowler, New Haven City Surveyor, for the heights of the various parts of the plain along the streets within the limits of the city; and to levelings by Mr. G. B. Chittenden and D. H. Pierpont, carried on under the direction of Mr. R. M. Bache of the Coast Survey, for heights through Hamden to Mt. Carmel.

Map of the New Haven Region.



Explanations of the map.—A, Allingtown village. B, Beacon Hill. Bh, Beaver Hills. Ch, Cherry Hill. C, Air Line Railroad cut, near south end of East Rock. E, East Rock range, consisting of East Rock proper to the northwest, Indian Head, and then Snake Rock. Ed, Edgewood, the estate of Donald G. Mitchell, Esq. F, Fort Hale. *F*, Ferry Point, or Red Rock, on the Quinnipiac. J, Judges' Cave, on the West Rock ridge. L, Light House. M, Mill Rock. M P, Maltby Park, only three of the proposed lakes of which are constructed. O, Oyster Point. P, Pine Rock. Rd, Round Hill. Rt, Rabbit or Peter's Rock. Sm, Sachem's ridge. T, Turnpike; also Tomlinson's bridge, across the head of New Haven bay. V, Whitneyville. W, West Rock, the south end of the West Rock ridge. W C, West Cape, or West Haven Point. Wh, Whitney Peak. W L, Wintergreen Lake, just north of Wintergreen Falls. Wn, Warner's Rock. *bm*, Beaver Pond Meadows; *m*, Mineral Spring, southeast of North Haven; *n*1, *n*2, *n*3, *n*4, different notches in the West Rock ridge; *n*1, *n*2, the upper and lower Bethany Notches; *n*3, the Hamden Notch; *n*4, the Wintergreen Notch.

Scale 4-10ths of an inch to the mile.

The part of the plain stretching northward through Hamden to Mount Carmel village, reaching there a height of about 115 feet above the sea, owes its slope to the pitch of the flooded stream, which there flowed over a sandstone region with no deep channel to confine its waters and direct their course. That it was not due to marine submergence to a depth of 115 feet is proved by the facts in the adjoining Quinnipiac valley, a mile and a half to the eastward. For at North Haven, six miles north of New Haven, the stratified drift or terrace has a height above flood level not exceeding 45 feet; and this is but two feet above its level five miles to the south, just north of west of New Haven city; facts which show that there was a nearly level surface over the great Quinnipiac basin or harbor between these distant points, and that the greatest height of the marine submergence, if there was one, could not have exceeded 45 feet.

If then the upper part of the sloping plain from Mount Carmel southward was made by fresh waters from the melting glacier, shall we conclude that this was true also of the lower part, nearly to the West Haven shore? The slope of this lower part is no greater than that more to the northward; and hence there is little objection to the conclusion from this source. The bay is small and throughout shallow, being but 3 to 18 feet deep at low tide, and little of it over 12 feet; so that it did not afford a capacious channel for the escape of the flood waters.

2. *Height of the terrace-plain above flood-level in the estuary and river-valleys.*—About the New Haven bay, the plain, as has been stated, rises gradually to the northward. It reaches its greatest height above the lower flats or flood-plain of the streams near where they leave their valleys to pass through the plain.

A. *West River.*-The greatest depth of the cut along West River, or greatest height of the terrace-plain above the lower flats, exists near Westville, where it is 45 to 47 feet. Going up West River this height above flood-level diminishes to 33 feet in the course of a mile, and to 6 to 8 feet in the next half a mile; but this is due to the rapid descent in the stream, which is 22½ feet in the first mile, and 50 feet in the following half a mile, 72½ feet in all.

B. *Mill River.*—Along Mill River, the height of the terrace for the first mile and a quarter above the head of New Haven bay, that is, through the New Haven plain, is ten feet or so below the height normal to that part of the plain; and this was a consequence of the denudation by the Glacial flood, as before explained.* But at Whitneyville, near the dam, the height—or the depth of the cut—is 50 feet; and this continues to be the depth up stream for the next mile and a half; and for the next three-fourths of a mile, or up to Augurville, the height is 45 feet. Toward Mt. Carmel village the height diminishes to 36 feet above flood level; and then in the next half mile above to 25 feet.*

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* This volume, page 177.

C. *Quinnipiac River.*—The terrace plain along the Quinnipiac near where it leaves its valley, or at the Air Line Railroad cut, is 43 feet. North of this lie the wide marshy flats, which continue for five miles to North Haven; and at the latter place the height of the terrace on the west of the river is but 45 feet; the waters having stood nearly on a level between the northern and southern limits of this great interior basin.

These are the facts from the river-valleys. Along each the cut made by the denuding waters since the Glacial flood is not far from 45 feet. This depth of cut is just what would at the present time result from the denuding action of the rivers, if the land were to be raised 45 feet or so—supposing there were no rocky ledges in the beds of the streams to prevent excavation downward.

On the other hand, if the Glacial flood were vast enough to raise the waters to that level and so to build up (out of the sands and gravel within its disposal) the drift formation there existing, without any aid from an elevation of the land, or of one of only 5 to 10 feet, then, when the flood had passed, the streams would have sunk their beds to their present level, and so have left the terrace-plain, where not more or less washed away, at its present height above them.

Thus either hypothesis, (1) that of an elevation of 45 feet since the Champlain period, or (2) that of the accumulation of stratified drift in the valleys to its present height by the Glacial flood, with little or no subsequent elevation of the land, will explain the facts. If the former were the actual condition, then the waters would have continued their work, about the estuary or inlet, of building Champlain deposits up to, or toward the 45 foot level, through all the Champlain period, or until the elevation of the land closing the period began. If the latter, the sinking of the rivers as the flood subsided would have lowered their working ground down to the existing level of those plains; and hence, little or no estuary deposits of the later or "Alluvian" part of the Champlain period, beyond a height of 5 to 10 feet above high tide level, should be looked for.

For further evidence we proceed now to facts from the *structure* of the beds of stratified drift, and from the occurrence of

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*** This diminution in the depth of the cut, or in the height of the terrace-plain, to only 15 feet, is owing to a trap ledge which crosses the bed of the stream in a line with the trap ridge at Mt. Carmel; this ledge prevented excavation.**

deposits of the later or "Alluvian" part of the Champlain period.

3. *Structure of the beds formed.*—Throughout the stratified drift-deposits of the New Haven region for four and a half miles north of Savin Rock on the West Haven coast, the finer beds of the stratified drift are characterized by the flow-and-plunge structure; and the oblique lamination in it—certain river valley regions excepted—*rises to the northward* (that is, dips to the southward). This *rising to the northward* I have attributed, in a former part of this memoir, to movement from the southward in the waters, that is, to plunging waves accompanying the *inflowing* tides—supposing that ordinary inflowing tidal waters may push up the sands of the bottom before them and so make ordinary obliquely-laminated layers dipping seaward or rising landward: and that, by the addition of plunging waves, the flow-and-plunge structure produced would also have the layers dipping seaward. That in such a case the dip of the little layer would be seaward I inferred, perhaps without due consideration, from the direction of movement in the water, and from observations long since made by me on the sandstones in the vicinity of Sydney, New South Wales.* If, as assumed in Part I of this memoir, the above conclusion is correct, the seaward dip of the oblique laminæ beneath the New Haven plain, up to a height of at least 45 feet, is proof that the sea was the agent, and that therefore the land at the time was at least 45 feet below its present level.†

Further, the deposits through the long Air-Line Railroad cut at the mouth of the Quinnipiac valley, have, as described on page 175 of this volume, the oblique lamination in the upper stratum of 20 feet *reversed;* that is, dipping landward instead of seaward; and this difference in the lower and upper strata naturally suggests that there was a change in the direction of movement of the depositing waters; a change from that of the inflowing tide to that of the outflowing flood, as stated on page 176; or, if the lower stratum was made by the flood, from the outflowing flood to the inflowing tide. Either way we reach the conclusion that, at some time in the early Champlain period, if not through all of it, the land was at least 45 feet below its present level, and that a rise to this extent has since taken place.

Still certain facts dispose me now to question the inferences that oblique lamination made by the inflowing tide would have the dip in general seaward, and that the reversion of the dip in the upper twenty-foot stratum on the Quinnipiac has no other explanation than a change in the direction of the current. Among them, I here mention only that I have observed several cases along river-valleys, out of the reach of the sea, of dip in both directions; and, in some of them, obliquely laminated layers dipping down stream had a thickness of several feet. Such facts bear against the view.*

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* See the writer's Exploring Expedition Report, 4to, 1849, pp. 465, 523. The observations were made in 1839.

† Owing to the want of good sections I have been unable to study the character of the lamination over the Hamden Plains, where the height of the surface rises beyond 45 feet.

4. *Alluvian Deposits*—Another fact favorable seemingly to the conclusion that the land remained 40 feet or more below its present level for some time after the Glacial flood had passed, is afforded by the existence of the deposit of horizontally-bedded white sands against the northward slope of the terrace of stratified drift at the northeast extremity of the Air Line Railroad cut, near south of East Rock. The figure is here reproduced that the relation of the deposit to the stratified drift may be appreciated. The conclusion, explained on p. 180, that the white sands were washed and accumulated on the south shore of a great "Interior basin" occupying the Quinnipiac valley, appears to be the only reasonable one; and if so, this "Interior basin" continued to exist for a while after the flood and flood-depositions had reached their height, as an area of high water. Yet, as the bed is of very limited extent and the terrace formation is generally free from Alluvian deposits, the time may have been only that of the latter part of the flood, prolonged after flood-deposition had ceased by the melting still going on to the north; and the region of melting may have been north of the head of the New Haven streams, since it is possible, as I show beyond, that the flood waters of the Connecticut and Farmington rivers overflowed into the New Haven region and bay.

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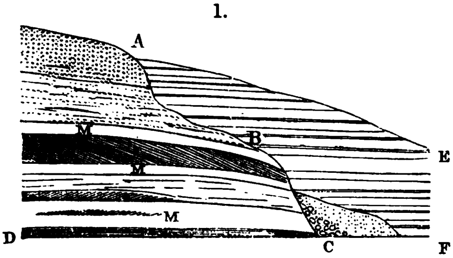

Section of stratified drift, A C D, and later unconformable Champlain deposits, A C F E, Air Line Railroad cut.

5. *Conclusion.*—While the height of the terrace-plain above the sea and its height above the flood-plain of the river, fail of demonstrating that the New Haven region was below its pres-

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* The gentle pushing of the waters over sands makes ripple-marks, or elevations having a seaward and a landward slope. The query now is whether, in the heavy pushing producing the oblique lamination, the laminæ would conform to the former or the latter of these slopes.

ent level in the Champlain period, the evidence from the structure of the beds and from the Alluvian deposits suggests that the region was submerged to a depth of at least 45 feet.

But if so deeply submerged, why should the terrace plain slope off gradually toward the coast and have no line of old beaches across it? And why is there no 45-foot sea-shore formation or terrace along some part of the bases of the hills?

The ways in which such a slope in the plain may be supposed to have resulted are the following:—(1) By a subsidence causing a bending downward of the coast-region after the elevation of 45 feet had taken place.—(2) By an elevation of the land which should be 45 feet four miles from the coast, but 10 to 12 feet near the coast.—(3) By the sweeping action of the flood giving a slope to the deposits toward the Sound and beneath its waters, and preventing the formation of seashore flats at the water's level.—(4) By the denuding action of the waves and tidal currents as the land rose to its present level.—(5) By the deposits, because of a diminution in the amount of material southward or increase in the depth of the waters, conforming in slope to the pitch of the surface on which they were spread out.

The first and second of these ways have little probability in their favor. The others I make the chief source of the result in my memoir on the New Haven region, saying (p. 99) after remarks on each method: "That part of the rapidity of slope in the lower portion of the plain below 40 feet in height is due to tidal, wave and river action over the region of the bay; and part to increasing depth over the borders of the bay southward and a decrease southward in the amount of transported sand." How far these methods are sufficient may be better considered after a survey of the facts from other parts of Southern New England.

2. THE LOWER PART OF THE HOUSATONIC VALLEY.

On page 409 I have stated that the height of the terrace of stratified drift in the Housatonic valley near Birmingham is 95 feet above high-water level. The terrace has the same height at Birmingham, and at the manufacturing village of Shelton on the opposite side of the river.* These places are situated at the junction of the Naugatuck river with the Housatonic. The Housatonic river comes down from the northwest, and the Naugatuck from the north; and on the point of land between lies Birmingham, with Shelton opposite on the west (or southwest) bank of the Housatonic, and the village of Derby on the east bank of the Naugatuck. The streams rise in the high regions of Western Massachusetts and Connecticut, in part over 1000 feet above the sea, and flow in rapids through much of their course down to their confluence, where they reach tide-level, ten miles from the Sound.

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* For this altitude I am indebted to measurements by Mr. D. S. Brinsmade, of Birmingham, surveyor. The leveling was made at Shelton, and gave for the average height of the plain above low-water 106·64 feet. Mr. Brinsmade states that some points were five to eight feet above this. I have taken as the maximum height of the terrace 112 feet. The height of flood-level above low water seldom exceeds 17 feet; and this subtracted from 112 gives 95 feet for the height above flood-level. A higher flood, Mr. Brinsmade says, occurred in 1857, when the river rose to 22 feet 3 inches.

As Birmingham is but nine miles to the westward of New Haven, it is improbable that the amount of elevation which the two places have undergone since the Champlain or Fluvial period should differ much; and hence there must be a special cause for the great height of the Housatonic terrace. For this cause we have only to look to the topographical conditions of the region.

Besides the fact of (1) the junction there of two rapid streams, whose united drainage area is about 1800 square miles, there are the following additional facts bearing on the subject:

(2) Both streams at that place have narrow terrace regions, the valleys between the hills having little width.—(3) On the east side of the Naugatuck the high bordering hills leave almost no space at their foot for the one-street village of Derby, so that the flooded waters cannot spread in that direction, and are naturally forced over against Birmingham and Shelton.—(4) The hills that lie back of Shelton, embaying its terrace region, reach to the river just below the village, and so do those on the Derby side, making thus, below Derby, a comparatively confined passage for the united waters, which has long been called the "Derby Narrows."—(5) The river channel below Derby, through its ten miles to the Sound is very shallow, being navigable for vessels drawing four feet of water only at high tide; and besides there are sandbanks at its mouth reaching a mile and a half beyond.—(6) The terrace along the valley below the Narrows is narrow for nearly seven miles out of the ten, the width in no part exceeding two-thirds of a mile.

Under such circumstances it is natural that the waters of the Glacial flood plunging down the two valleys should have entered the region of Birmingham and Shelton faster than they could have escaped. The fact that a cataract of great volume passed the region of Birmingham and dashed violently against the Shelton shore is abundantly manifested by the multitudes of large water-worn rocks and thick coarse cobble-stone deposits in the upper portion of the lower as well as high upper terrace, and in the imperfect stratification of portions of the deposits.

Even modern floods in the region bring down waters faster than they are discharged through the Derby Narrows and the channel beyond. The Housatonic river below the confluence has almost no slope at high tide, the tide reaching that point. Yet a spring flood often produces a rise of 17 feet at Shelton, and causes an average pitch in the river's surface for the ten miles to the Sound of nearly 1¾ feet per mile; and there is occasionally a flood causing a rise of 22 feet, and consequently an average pitch of more than 2 feet a mile.

To ascertain the average pitch below Birmingham or Derby for the Glacial flood we have important data in the height of the upper terrace between these places and the Sound.

The Shelton and Birmingham level of 95 feet extends below Derby to the "Derby Narrows." Below the Narrows—about 1½ miles from Shelton and 1 mile from Derby—the valley on its *east* side expands rather abruptly about the mouth of Two-mile Creek; it then contracts again on that side, through the rising of "Turkey Hill," but regains its expansion below through the retreat of the hills on the *west* side.

Now the terrace below the Narrows, just north of Two-mile Creek, has a height of 75 feet above high-water mark; and a mile below this, on the west side, of 70 feet. Hence, in passing the Derby Narrows, a distance of three-fourths of a mile, the level appears to have fallen 20 feet, which would indicate a tremendous rush of waters between the rocky hills.

The following table contains the heights of the terraces as measured along the valley to the Sound, the above included:[*]

			Feet.
At Shelton, opposite Derby			95
1 m.	below Derby,	east side, below the Narrows	75
2 m.	"	west side	70
4 m.	"	east side	50
5 m.	"	east side	46
6 m.	"	west side	43
6·8 m.	"	west side, near a stream	35
7·5 m.	"	½ m. above Railroad crossing	31
8·25 m.	"	near Stratford bridge	30
9·75 m.	"	½ m. from the Sound	12–20

The average decline in the height of the terrace from Birmingham, where, being 95 feet above flood-level, it is 100 above tide-level, to the Sound is over 10 feet a mile.[†] The rate of decline should not be uniform because it would vary with the varying width of the valley and depth of the channel. Moreover, in the case of most terraces, it is not certain that they were built up quite to the surface of the flood. The fact of a slope in the waters is, however, proved, and the general amount of pitch seaward deduced cannot be far from the truth.

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[*] The heights given in this memoir, where not attributed to others, were obtained by the writer, and all of them with a hand-level, excepting four, above 120 feet, which were measured with a good aneroid.

[†] Five miles below Derby, west of the Housatonic, and one mile up its tributary, Farmill River, I found the height of the terrace 60 feet. This height was, however, that of the tributary, and not properly that of the Housatonic.

For determining the actual amount of elevation along the lower Housatonic since the Champlain period no satisfactory data have been obtained. It is plain that the height of the terrace at Birmingham is a measure chiefly of the vastness of the flood, and that the "necessary deductions" for reducing it to a measure of elevation are very large. The evidence with reference to the elevation derivable from the structure of the beds could not be studied for want of sections. The wide extent of the thirty-foot terrace-plain suggests that it may mark the Champlain water-level; but of this other proof is needed. The formation of the seashore terrace would not require an elevation of more than 12 or 15 feet.

3. THE LOWER PART OF THE CONNECTICUT RIVER VALLEY.

The height of the stratified drift deposits in the Connecticut River valley at Middletown, 150 feet, seems, at first thought, to be evidence of a very great change of level since the era of deposition, much greater than in other parts of Southern New England. But what part of the rise in the waters was due to the great flood? The Connecticut River passes through the whole length of New England from north to south, and has a drainage area of about 20,000 miles. The melting glacier would have continued to augment its waters through its long retreat from the Sound to the borders of Canada..

First, a few words on the condition of the river supposing the Glacial flood to have raised the waters to the height mentioned; and, then, the facts which prove that such was the height and extent of the flood.

The Middletown region, 30 miles from the mouth of the river, with the floods at a height of 150 feet above the modern flats would have been in the condition of a lake one to four miles wide, and over part of the area, 100 to 150 feet deep. This Connecticut valley lake would have extended northward, narrowing and having shallow borders between Cromwell and Glastenbury (or between 3½ miles and 11 miles from Middletown), then widening again so as to cover an area a dozen miles in width about Hartford. I am informed by General T. G. Ellis, recently in charge of the Government Survey of the Connecticut River, that the stream at low-water at Hartford (15 miles north of Middletown) is on a level with mean low water in the ocean. Passing Hartford, it would have continued to Springfield and beyond; but it was probably in this part a broad rapid stream, with shallow borders most of the way on either side of its main channel, and having part of the pitch of the present stream, about 38½ feet in its course between

Springfield and Hartford, a distance of 24 miles. The whole width of the waters at Springfield was probably greater than at Hartford, although averaging much less—as the height of the terrace near the river shows—in depth. The Springfield level extended 10 miles to Holyoke, where are the South Hadley Falls of 60 feet.[*]

The evidence as to the reality of this height and of the great breadth of the waters is as follows:

Three-and-a-half miles north of Middletown, east of the river, a broad terrace rises boldly from the river to a height above flood-level of 144 feet,[†] and the wide plain continues, with a nearly even summit, though mostly of greater height 150 and 155 feet, to Glastenbury, eight miles to the north. The road from Middletown to Hartford on that side of the river, for the most of the way, is on the terrace. In addition to its level features, there is other proof that the formation beneath is the true stratified drift in its consisting, as shown in sections, of stratified sands and gravel. A terrace at very nearly the same height exists also for part of the way on the west side of the river in the town of Cromwell. The coarse nature of the beds comes from the rapid flow of the waters, and this from the little depth over the region where they were deposited—a fact made manifest by the sandstone rocks showing themselves occasionally through the plain. About Middletown, where the depth was great, the deposits consist of fine earth and clay.

Prof. Hitchcock, in his "Surface Geology," gives the height of the South Glastenbury "terraces" as 175 feet above the river, which would be about 152 feet above flood-level.[‡]

In the city of Middletown, the corresponding terrace is distinct between High street and the next street west, north of the grounds of the Wesleyan University, and has a maximum height of about 150 feet; and these grounds, excluding a portion in the southwest corner, are part of it. A terrace two miles east and southeast of Middletown, above where the river narrows, I found to have the same height—150 feet.

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[*] Nearly 32 feet out of the 38½ of descent between Springfield and Hartford is made along Enfield Falls, beginning 8 miles below Springfield and continuing for 5 miles over a rocky bottom.

The height of the Holyoke dam at either end is 97·60 feet above low-water mark at Hartford, or mean low water in the ocean.

The tide up the Connecticut River is sometimes noticeable as far as Windsor Locks, at the lower limit of Enfield Falls, 10 miles north of Hartford. The highest in summer at Hartford, 45 miles from the mouth of the river, has a range of about 10 inches; and that at Middletown, of 1·93 feet.—*Gen. T. G. Ellis, in Reports U. S. Engineer Dept. for* 1868 *to* 1874.

[†] For the height of the terrace at this point I am indebted to a leveling by the following persons connected with the Sheffield Scientific School: Mr. G. W. Hawes, assistant in the Mineralogical department, and H. A. Miller, H. Hun, and A. B. Howe.

[‡] Prof. Hitchcock suggests in his "Surface Geology" that the terrace at South Hadley of "292 feet" above the ocean, and that at Willimantic of "268 feet" slopes southerly, and corresponds with that of "200 feet" at Springfield and Long Meadow (136 feet above the river), that of East Windsor of "96 feet," and that of Hartford of "61 feet" above the ocean. Such a slope is impossible; and further, the wide Glastenbury terrace, which he here leaves out of consideration, proves it not to have been a fact.

Immediately around the city of Hartford the plain is mostly 40 to 60 feet above high flood-level in the river (70 to 90 above low-water); and in many places it consists of clay to the top. But beyond three or more miles there is a rise to higher levels.

Northwest of Hartford, along the Connecticut Western Railroad, the plain is extensive 6 to 7 miles out at a height near 130 feet, and between 9 and 9½ miles, at a height of about 160 feet.*

East of Hartford, the terrace has a maximum height near Manchester, 7 miles out, of 155 to 160 feet.

South-southwest of Hartford, the extended New Britain plain is 142 feet in height above the same base—high flood-level in Hartford.†

The facts appear to point to a height of about 160 feet for the upper terrace of the Connecticut valley, that is, for the glacial flood, in the vicinity of Hartford.

Sixteen miles south of Hartford, on the railroad route to New Haven, the broad divide between these two cities—1½ to 2 miles north of Meriden—has its highest part made by a terrace of stratified drift, (rising 20 to 21 feet above the railroad track); its surface is about 185 feet above mean high tide at New Haven, and 158 feet above flood-level at Hartford, and it is probably, therefore, a Connecticut River terrace;‡ and since it has a depth of more than 20 feet, the Connecticut during the glacial flood must have lost some of its waters by their spilling over the divide into the Quinnipiac valley and river.§

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* I learn from Mr. W. H. Yeomans, the Superintendent of the Connecticut Western Railroad, that the height of the track 9½ miles out, near Scotland, is 190 feet above mean tide level, which is equivalent to about 160 feet above highest flood at Hartford.

† Mr. S. C. Pierson, of Meriden, has informed me that the height of the New Britain plain is about 172·25 feet above mean sea-level, which is 169·12 feet above mean high tide, and about 142 feet above highest flood-level at Hartford.

‡ A leveling from Meriden to the divide, for the height of the divide above the crossing of Main street and the railroad in Meriden, gave Mr. S. C. Pierson 43·64 feet; which, with 121·50 for the height above mean high tide, and 20 feet for the terrace, gives for the height of the divide above high tide, about 185 feet; or 158 feet above the Hartford flood-level. A careful barometric measurement at Meriden by Mr. E. S. Dana, obtained for the height of the track by the Meriden depot above high tide, 127·3 feet; which would give 191 feet for the whole height of the divide above high tide, and 164 feet for the height above Hartford flood-level.

§ The evidence favoring the view that waters from Farmington River poured down the Quinnipiac during the glacial flood is even more conclusive. Prof. Hitchcock has suggested (Rep. Geol. Mass., 329) that the Connecticut may have contributed to the Farmington along a route west of Mt. Tom and over Westfield and Granby.

At Springfield, within a mile or less from the river, there commences the great terrace of the region—a plain several miles wide—having a height, as I am informed by Mr. G. A. Ellis, city engineer, in general between 140 and 145 feet above flood-level in the river (the higher floods raising the river about 22 feet), or about 200 feet above high tide. But this wide terrace shows, by the fact that the material of it is mostly fine sand and clay, that it was made in comparatively quiet waters before the flood was at its height, and that it is probably not the highest. Beyond three miles southeast, east, and northeast of Springfield there are hills of stratified sand and gravel, rising to a height of 180 feet above flood-level, which belong to the *upper* terrace, and mark more nearly the flood's height. I learn from Mr. Ellis, to whom I am indebted for a map of Springfield and its vicinity for ten miles around giving the amount of elevation for a large part of the surface, that this 180-foot level (or 170 to 190) occurs in hills made of hardpan near the Boston and Albany Railroad, 3 miles from the Springfield depot; and south of this, near the "Old Bay Road." A level of 180 feet occurs along the same railroad between 6 and 9 miles from the depot, or for 3 miles east of Jenksville. Traversing the region with Mr. Ellis, he has shown me that the 180-foot level extends from Jenksville northward, with little variation, toward the Granby line, over four miles, if not beyond, and westward five to six miles to the Connecticut river. At Willimansett, on this part of the river, Prof. Hitchcock measured the height of the terrace and found it 172 feet above flood-level (or 194 feet above low water); and at South Hadley, two miles north of Willimansett, he found nearly the same height.

The upper terrace is therefore not less than 180 feet above flood-level in the river (or 237 feet above high-tide level in the Sound,) and probably this is very near the true height.

Ten miles east of Springfield, at Collins Station on the railroad, there is a plain, as Mr. Ellis informs me, at a height of 210 feet. But this is partly confined by the Wilbraham Hills, and is properly the terrace of the Chicopee river, which is but three-fourths of a mile distant. From Mr. Ellis I learn further that in Westfield, 10 or 11 miles west of the Connecticut, the land rises into a plain of great extent, being two miles broad, "widening between Westfield and the point where Westfield Little River leaves the town of Russel," which has a general elevation of 205 above flood-level in the Connecticut, or, 262 feet above high tide, "corresponding very closely with the plain-region the same distance to the east of Springfield." But this Westfield plain is in the Westfield valley, and is properly a Westfield river terrace. Yet if these higher flood-grounds, extending to a distance of 10 miles on the east and west, were outside of the limits of the Connecticut flood, they indicate that the waters were pouring into the central trunk in vast volumes from the regions either side, and also that the same flooded condition characterized all New England valleys.

The depth of the flood-waters and their great width along the Connecticut valley cannot therefore be questioned. Now what does this great height of the upper terrace indicate with regard to the depression of the land when the deposits were made, or the elevation since that time? What are the "necessary deductions?"

1. Two miles below Middletown, the Connecticut river passes between high and steep rocky slopes, and has a width of but 400 yards; and when the old flood was at its height, the width was even then not over 500 or 550 yards, not a tenth of that at Middletown. These "Straits" or Narrows extend for two-thirds of a mile; there is then some widening on the east, and a mile below, as much on the west, giving room for the terraces of Middle Haddam and Maromas. Thence the valley continues southward with more or less room for a terrace on the west side and little or none on the east, the valley, reckoning to the limits of the terrace, seldom much exceeding half a mile in width.

The Narrows below Middletown, like the Narrows on the Housatonic below Derby, had evidently much to do with determining the great height of the flood-waters above. The waters could not pass off by the contracted outlet as fast as supplied by the melting glacier, although this outlet was over a fourth of a mile wide; and hence the waters were piled up high over the back region. This effect is imitated on a small scale with the melting of the winter ice and snow causing the spring floods; the water at Middletown increases its height at the highest floods about 25 feet, which is equivalent to increasing its average pitch thence to the Sound by five-sixths of a foot per mile.*

There is evidence that a very large part of the 150 feet was actually due to the flood. This is found in the descending

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* The height of the floods at Hartford is 4 to 5 feet above that at Middletown. I owe to General Ellis the following table of flood heights at the two places. The low water at Middletown from which they are measured is 1·3 feet below the zero at Hartford, and the latter is ·045 foot below mean sea-level.

Flood of		1801,	Hartford,	27 ft.	6 in.	Middletown,	23 ft.	8½ in.
"		1843,	"	27 "	2 "	"	22 "	11 "
"	April,	1852,	"	23 "	1½ "	"	19 "	5 "
"	Nov.,	1853,	"	20 "	6 "	"	17 "	2 "
"	May,	1854,	"	29 "	10 "	"	25 "	8½ "
"	Aug.,	1856.	"	23 "	4 "	"	18 "	1 "
"	March,	1859,	"	26 "	5 "	"	21 "	10 "
"	April,	1862,	"	28 "	8 "	"	23 "	9½ "
"	March,	1865,	"	24 "	9 "	"	20 "	00 "

He remarks further that the average difference of the heights of the nine freshets is 4 feet 3½ inches, and the slope of the surface would be 1·3 feet more than the difference of the heights.

height of the uppermost terrace of stratified drift along the river to the Sound. The heights, on the west side of the Connecticut, going *southward*, are as follows:*

2 m.	below	the Narrows,	the Maromas plain	133½	ft.
5 m.	“	“	near Higganum	100–105	“
7½ m.	“	“	near Haddam station	82– 85	“
10½ m.	“	“	near Goodspeed's station	75	“
14 m.	“	“	near Chester station	60– 62	“
20 m.	“	“	1½ m. below Essex	42– 45	“
22½ m.	“	“	near ferry and railroad	30– 31	“
24½ m.	“	“	Saybrook Plain	20– 21	“
26 m.	“	“	Seashore House, on Sound	13½	“

The plains, the heights of which are here given, were well displayed, leaving no doubt that they corresponded to the true terrace; and they were the highest in each region. They show that, from the Narrows, the river waters plunged along with a pitch of several feet a mile.

It may seem almost incredible that waters so violent should have made terraces in many places along the sides of the narrow valley. But the material of these terraces—mainly sand and coarse gravel, and the coarser above as usual—was to a large extent washed in from either side by the waters descending the side valleys, ravines, and all sloping surfaces; for there was gravel and sand everywhere over the hills from the dissolving glacier, and water everywhere in profusion for the work of transportation. The waters merely stratified and leveled off at top the material thus contributed. Moreover, we can follow the rise of the flood in the succession of the deposits; in clays, in some places, near the bottom—one bed supplying a brickyard just below the Narrows—made when the waters were yet low; the sands next deposited while the waters were rising; the fine and coarse gravel mostly above—at the top of the lower, as well as of the highest terraces—spread out when the flood was at its height. The Middletown region is mostly one of fine earth, and the sand and gravel of the terraces below the Narrows could not have been carried over it by the stream, without making large depositions,—except in ice-floes, and these certainly did little of the transportation in the case here referred to.

Finally, how far was the height of the terraces described due to an elevation of the land since the beds were deposited?

Judging from the seashore terrace, on Saybrook point, the elevation of the land did not exceed 15 feet. I have not succeeded in finding other evidence on this point.

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* The height of the Maromas plain was determined by levelling, by Messrs. Pillsbury and Clarke, of the Wesleyan University. They obtained 133½ feet above flood-level. The extended terrace on the opposite (east) side of the river has about the same height. The other measurements were made by the author.

4. THE RIVER THAMES.

The conditions of the stratified drift deposits of Norwich are similar in several respects to those about Birmingham. Two rivers from the northward, the Quinebaug and the Yantic, pass either side of the city and unite below it to make the Thames. They rise in Massachusetts, and have nearly the same drainage-area as the two that join at Birmingham. They descend from high land and most of the way in rapids. Immediately below Norwich the valley is so narrowed by hills over 150 feet high that the width of the river, were the water 100 feet above its present level, would be hardly half a mile. But below these Narrows the valley expands, though still closely bounded by high land. The points in which the two cases differ are these:

(1.) The Narrows have greater width, and the modern stream below has much greater depth as well as breadth: the channel being one of the tidal, navigable fiords of the coast, the tides at Norwich having a range of more than three feet. Consequently it offered the flood-waters a less contracted way to the Sound.

(2.) The distance from the Narrows to the Sound is greater, being 14½ miles.

(3.) Although this distance is so much greater, the highest spring floods cause a rise above high tide of but 7½ feet—much less than half that in the Housatonic at Birmingham.

Again, (4,) the terrace plain of upper Norwich—the site of Broadway and its many fine residences—has over its northern part (at the foot of the little triangular Green) a height above tide level of 117 feet;* and, since the spring floods raise the water but 7½ feet above high tide, about 110 feet above flood level, against 95 feet at Birmingham.

The height of the Norwich plain above flood level diminishes from 110 in its northern part to 101 feet in its southern, a distance of about a mile; and this is very nearly the level of the terrace to the eastward of the latter at the Old Cemetery. The Norwich plain is so extensive, and the deposits so clearly consist of bedded sands and gravel, with the flow-and-plunge structure in some places quite to the top, that there is no occasion to doubt the statement that the water once stood at its high level. And since the deposits—those beneath the Old Cemetery, for example,—are made up in places of the coarsest gravel, the waters were the hurrying waters of a great torrent.

That this was the actual condition is proved further by the heights and nature of the terraces below Norwich. For they

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*** I have these numbers from the Water Commissioner of the city of Norwich, Mr. Winship. I have been much aided in the study of this region by a map of the Thames, giving contour lines for 50, 100 and 200 feet, which was furnished me by the Superintendent of the Coast Survey.**

declined southward, precisely as in the Housatonic and Connecticut River valleys. The heights are as follows:*

Highest part of Norwich Plain,			110	feet.
1 m.	South,	on Norwich Plain,	101	‘
2½ m.	“	at Thamesville, below the Narrows,	88	“
5½ m.	“	near Mohegan R. R. Station,	75	“
8 m.	“	½ m. W. of Montville R. R. Station,	61	“
10½ m.	“	in Smith’s cove, 250 yds. W. of R. R.,	50	“
13½ m.	“	at New London, northeastern part,	24–25	“
14 to 16 m.	“	between New London and the Lighthouse, none distinct.		

Below the Narrows the valley opens widely on the west about Thamesville, and consequently has there a broad terrace. The same is true also of the region and terrace of Montville where a lateral valley comes in. The material of the upper part of the formation on the river near the Montville railroad station is very coarse, some layers being made up largely of cobble stones. On the point just north of Smith's Cove, the terrace is only 25 to 27 feet high; but it shows that it is below the normal height by its stony character; and, further, just around the point, 250 yards inside of the Cove, there is a much more extended terrace at a height of 50 feet, made of finer material.

The terrace in the northeast part of the city of New London (near where the track of the Northern Railroad leaves the city) is also very stony, and must be below its normal height, and probably as much as ten feet.

In passing the Narrows to Thamesville the decline of the terrace plain is 13 feet; and below Thamesville to Smith's Cove, on an average nearly five feet per mile. This last pitch if continued to New London would make the normal height there 35 feet instead of 25 feet. The terrace is equally low on the east side of the Thames in Groton; but it is also very narrow there, little room existing at the base of the hills for a terrace.

South of New London, between it and the Sound, I saw no distinct terrace.

The decline southward in the height of the terrace plain, as in the case of that along the other rivers, does not suggest marine action as the means of deposition. It manifestly points to the pitch of flowing waters in the channel, and to such a flow as could exist only in a period of incredible floods—when an outlet averaging over half a mile in width was not wide enough to discharge the waters coming from the hills and valleys within a range of forty miles.

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* For the height of the plain near the Montville Station, I am indebted to a levelling by Mr. C. P. Jennings, Surveyor of the city of New London.

Direct evidence as to the actual level of the coast about the mouth of the Thames during the era is wanting; both because of the absence of a seashore terrace, and because no sections were exposed along the Thames that afforded a chance for studying satisfactorily the character of the bedding. But if the New London Lighthouse Point is without terraces, I have seen several examples of them at the head of broad bays between New London and Stonington, and in no case have I found the height over 15 feet, and generally it is but 10 or 12 feet. Again, Fisher's Island—about seven miles in length—lies off this same coast, and within five miles of it; and at the head of West Harbor, there is a well defined shore terrace of 15 feet; and, at East Harbor, one of less certain nature nearly 25 feet. 25 feet is therefore the greatest height inferable from this kind of evidence, and 15 may meet the facts.

5. NARRAGANSETT BAY.

Providence is situated on Providence River within a mile of the head of Narragansett Bay. Its terrace, averaging 80 feet in height above high water, is extensive, and part of the city is built upon it. The river opens into the broad northern arm of the Bay, and affords 14 feet of water for shipping to the city. The Bay has passages one to three miles in width among its islands, and enters the Sound about 26 miles south of Providence. With so open a passage for the waters we might infer that certainly the Providence terrace must mark a sea level of the Champlain period. But in view of the facts detailed in the preceding pages it is evident that something of this height is attributable to the flood descending the river valleys.

I have not been able to study carefully all the shores of the great bay with reference to its terraces. Ten and a half miles south of Providence, east of East Greenwich, there is a very wide terrace-plain, which extends south toward Wickford. Near the railroad in East Greenwich, the height is 56 feet, showing a loss of 24 feet of elevation in the 10½ miles from Providence. At Wickford, 7 miles farther south, the height is much less, little exceeding 30 feet.

There is a terrace at Fall River, on the west shore, about 17 miles from the Sound, and between this place and Tiverton. The height, just below the depot at Fall River, is 35 feet above high water; but the beds are very stony toward the top, and hence it is that the terrace is 30 feet below the normal height; some of the stones are a foot in diameter. The terrace south of Fall River has no greater height. About Newport there appeared to be no well defined terrace.

But direct evidence bearing on the height of the region in the Champlain period is afforded by the coast region between

Point Judith (the west cape of Narragansett Bay) and Watch Hill (the cape south of Stonington). Along much of this shore, as stated on page 411, there are wide flat meadows between the hills and the sea, having a height of about 11 feet above high tide. The road passes between these flat meadows on the south, and the bowlder-covered hills on the north, and the contrast is very striking: the former sandy or gravelly and thinly grassy among the great bowlders, the latter having an even dense turf over a rich black soil. Above the level of the meadows no trace exists of sea-shore flats or beaches; the stony hill-sides rise gradually, with nothing about them to suggest a Champlain submergence.

Off this shore, one to two miles, there is a sandy barrier; rising into hills to the westward, and it may be questioned, therefore, whether the meadows may not owe a part of their height to the flood waters. But the black soil appears to be evidence that they long lay with the surface at the sea-level, perhaps as a salt marsh of the Champlain period. Large portions are thickly strewn with broken oyster shells, left by the Indians, and this may be one source of the fertility.

No marine relics have yet been found in Champlain deposits about any part of Narragansett Bay to mark the sea-level. Such fossils should be looked for with more care than has hitherto been used; but much looking will probably end in finding none. The great glacier must have filled the channels among the islands; and as the ice disappeared, the floods, having a strong pitch owing to the height at Providence, would have made a profound sweep through them. Absence of marine fossils is therefore what should reasonably be expected.

An 80-foot terrace at Providence, a 56-foot terrace at East Greenwich, and an 11-foot plain on the sea-coast with no trace of any other terrace-level on the coast hills, are the positive facts gathered from the vicinity of Narragansett Bay.

6. PRE-GLACIAL SAND-HILLS.

To define more clearly what are true deposits of stratified drift of the era of the melting in Southern New England, I add a few remarks on certain sea-shore sand-hills, that are easily mistaken for drift formations. I refer to ridges and hills of stratified material along the shores between Watch Hill and Point Judith.

It has long been known that Martha's Vineyard consists largely of Tertiary sands interstratified with clays, unconsolidated—except in some places through limonitic depositions making a limonitic or iron conglomerate. Block Island, Long Island, and Fisher's Island, just off the New England coast, are also made up to a great extent of such unconsolidated pre-glacial beds,—as I shall more particularly explain in another memoir.

The New England coast region, from Watch Hill eastward, is but a continuation of Fisher's Island, in its features, and also, as there is reason to believe, in its Tertiary deposits. Its hills or ridges are of various heights, up to 180 feet; and nothing besides unconsolidated, though bedded, sand, gravel and clay, occurs in their constitution. Clay-beds are not in sight. But near the Ocean House, one of the large Watch Hill hotels, a pond, near the sea-level, is called Clay pond, because of the clay beneath the water; and I am informed by a resident in the region, that masses of clay are sometimes thrown up by the sea on the beach, showing that it exists at the base of the sand hills.

Over the stratified material of the hills lies the unstratified drift, with multitudes of large bowlders .

These hills show that they do not consist of Champlain or later deposits by the following characteristics.

In the first place, the hills are, as stated above, covered throughout with bowlders, down to within 10 or 12 feet of the sea level, and this demonstrates that the hills were there before the deposition of the bowlders and the associated gravel and sand.

Further, the features as to the bowlders and the hills are just those of Fisher's Island, which lies in their line at a distance of only three miles to the west;—and not that distance, since there are intermediate islets and reefs connecting the two; and on Fisher's island the clay beds and sand beds which underlie the top-dressing of unstratified bowlder drift are in some places upturned and folded—proving thus their anterior origin.

We may hence set aside those sea-border ridges as not of the Champlain period, and regard them as prior in elevation even to the Glacial period. Only the low grassy plain at their foot along the shores is of the Champlain water-arranged drift formation.

CONCLUSIONS.

The observations described in the preceding pages relate only to five of the river valleys of Southern New England. Although I have made no systematic measurements of terrace-heights in other valleys, I have seen enough in many of them to assure myself that all have the same class of facts to afford. The conclusions which are here reached with regard to the river floods are therefore conclusions for all Southern New England, and beyond this, I believe, for all New England, and other regions covered by the great glacier.

1. The first question before us is—What was *the amount of depression* in Southern New England during the melting of the glacier.

The evidence that some elevation took place in Southern New England after the Champlain period, based on the existence of elevated flats along its sea-border, we may regard as conclusive. The height of the marine terraces where not modified by fluvial action varies between 5 feet and 25 feet, and rarely exceeds 15 feet. Taken alone, this affords no ground for believing that the elevation was less than 10 feet or greater than 25 feet. I think that 15 feet is the most reasonable inference, for the portion of the coast considered in the preceding pages.

The evidence derived from the structure of the bedding in the New Haven region—that is, the direction of the dip in the flow-and-plunge portion (p. 418) appears to be good; but since it is difficult to believe that the coast region of the Champlain period should have had no flats at the water level, to be placed, by an elevation of 40 feet, at a height of 40 feet, it is hard, in the absence of such terraces, to set aside all doubt with regard to that evidence. Hence, although at present unable otherwise to explain those facts, I am led to hold the conclusion in abeyance. This doubt is in opposition to my former statements. But those statements were based mainly on a study of the New Haven region, and the few facts from Connecticut previously on record. A decline in the height of the terrace-plain toward the Sound down to only 5 feet of elevation at the coast, along an estuary receiving three streams swollen by glacial floods, seemed to be accounted for satisfactorily by the sweeping action of the floods, and the erosion by waves during the progress of an emergence. But now that we know that such a seaward pitch in the terrace plains exists along all the valleys of Southern New England, and that the sea-coast terrace is universally but 5 to 20 feet in height, those causes appear to be inadequate. It is difficult to believe that they could have prevented so completely the existence of shore plains above the low height mentioned, through the whole line of coast, even (1) where no rivers sent down their floods, and (2) where distant barriers protected the shores from the heavier seas. Were the land 40 or 50 feet below its present level, as hitherto supposed, some of the islands off the coast would still have been a shelter from the heavier waves; and many of existing shore-hills would have been islands, protecting an inner region wholly from violent seas; so that deposits at or near a 40-foot or 50-foot level might well have been formed. And yet none such exist.

In the present state of the facts I therefore think that the argument for an elevation of only 10 to 20 feet is the strongest, although not yet decisive.

2. *The river-valley formations not marine.*—The ocean took no part in the formation of the river terraces. The pitch in the terrace plains of the lower Housatonic, lower Connecticut, and the Thames, is alone sufficient evidence against marine action in the matter.

3. *The height of the flood the chief cause of the height of the terraces.*—The facts from the valleys of the Housatonic, Connecticut and Thames prove that the river-valley formations—which now stand at so great a height above the river's surface—were not wholly, or for the greater part of their height, formed *when the land was at a much lower level than now ;* but, on the contrary, that they were formed *when the river's waters were at a greatly higher level than now*, and as a consequence, chiefly of the glacial flood. If the whole elevation of the land since they were made is but 15 feet, then the rest of the elevation of the high terraces was owing to the height of the flood.

The facts hence teach that we may have high terraces along valleys, and many terraces, and yet none be due to an elevation of the land. Further, the height of the lower terraces of stratified drift is *comparatively* of little geological interest. For, in New England, they cannot be proved to have had anything to do with successive stages of elevations; and, in general, they were underwater flats of different levels; or they originated as levels up to which the flood, according to its rate of flow, built the stratified material, or down to which they swept off that which had before been laid down; or they mark the level of oscillations in the height of the flood after this had reached its height.

4. *Height of the streams during the flood.*—The height of these valley formations above *flood-level* has been stated on preceding pages.

The following table contains these heights, and also the corresponding heights above mean *high-tide level.*

	Above flood level.	Above high-tide level.
On the Housatonic, at Birmingham,	95 feet.	110 feet.
On the Connecticut, at Middletown,	150 feet.	170 feet.
" " at Hartford,	160 feet.	185 feet.
" " at Springfield,	180 feet.	237 feet.
On the Thames, at Norwich,	110 feet.	117 feet.
Head of Narragansett Bay, at Providence,	80 feet.	80 feet.

To obtain the actual height above high-tide level, these numbers should be reduced by whatever was the amount of depression of the coast region during the Champlain period—that is by 15 feet, if that was the true amount.

Another reduction also is required.

The heights of shell-bearing beaches on the coasts of Massachusetts, Maine, the Labrador coast, Lake Champlain, and the St. Lawrence, show that the amount of depression in the Champlain period (or of elevation since) *increased to the northward.* If this was true along the eastern coast of New England, it was probably true also for the interior; indeed, Lake Champlain and the St. Lawrence at Montreal are part of the interior. Since the height of these beaches at Montreal have been shown by Dawson to indicate a depression there of 500 feet, and since that on the Sound was certainly not over 45 feet, and probably not over 15 feet, the average rate of increase from the Sound northward was about *one foot and a half* a mile.*

Adopting this as the average rate, the amount of depression in consequence of it was increased at Birmingham, 10 miles from the Sound, by 15 feet.

At Middletown, 20 miles in an air-line, by 30 feet.
At Hartford, 35 miles, " by 52½ feet.
At Springfield, 58 miles, " by 87 feet.
At Norwich, 15 miles, " by 22½ feet.
At Providence, 28 miles, " by 42 feet.

Providence, though 26 miles from the Sound, is 28 miles from a line having the course of the shore meadows west of Point Judith.

With an increase northward, in the depression, of only 1 foot a mile, the depression derived from the source here considered, would have been *one-third* less at each of the places.

5. *Pitch of the stream during the flood.*—Owing to this depression, the pitch of the streams seaward was diminished. From the above numbers we obtained for the *average* pitch of the rivers to the Sound approximately:

8 feet per mile below Birmingham.
4·5 " " " Middletown.
5 " " " Norwich.
1 foot " " Providence.

In the highest modern floods, the pitch is about two feet below Birmingham; nine inches below Middletown; six inches below Norwich; and not over one inch below Providence.

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* This subsidence, so much greater to the north over New England than to the south, must have occasioned, as I have stated in other places, nearly or quite a cessation in the movement of the glacier; and in this condition the ice appears to have melted away. One important consequence of this is the absence from New England of all terminal moraines. Terminal moraines are made from long-continued successive depositions of moraine-material (rocks, gravel, sand) at the terminus or melting-place of the *moving* glacier; and were there no motion none would form. On this account, the subject of terminal moraines has not been included in this memoir on "Southern New England during the melting of the great glacier."

Or, supposing the rate of increase of depression northward over *Southern* New England only one foot per mile, or less than farther north, the pitch would have been approximately:

8·5 feet per mile below Birmingham.
5 " " " Middletown.
5·5 " " " Norwich.
1·5 " " " Providence.

If the land were 15 feet below its present level along the southern coast of New England, and the average rate of increase of depression northward were 1 foot per mile, the height of the flood waters above high tide would have been

At Birmingham,	85 feet.
At Middletown,	135 "
At Hartford,	135 "
At Springfield,	164 "
At Norwich,	87 "
At Providence,	37 "

It hence appears that, with 1 foot a mile as the northward increase of depression of the land, the waters would have been at Hartford on the same level as at Middletown; and at Springfield, but 29 feet above the level at Hartford, instead of 38½ feet, the present difference; and the pitch from Springfield to Hartford would have been about a foot a mile. With 1½ feet a mile of increase of depression northward, the flood at Springfield would have been only 10 feet higher than at Middletown.

7. *Glacial conditions.*—Whatever the rate of increase northward in the depression, and whatever the amount of actual depression along the Sound, only a small part of the marvellous in the glacial flood is removed. The rivers in the lower parts of the Housatonic, Connecticut and Thames valleys were cataracts on a scale beyond all modern knowledge. The waters from the melting glacier must have been poured down the streams in vast volume to have piled to so great heights before outlets so wide and so deep. And such facts are but examples of a condition that prevailed generally over the glacier-covered lands.

6. *The Champlain a Fluvial period.*—It is to be remembered that the glacier consisted of the precipitated waters of many thousands of winters, each winter, too, a year in length. Hence, when the melting reached its height, some centuries of precipitated moisture were let loose at once. The results from the action of the great rivers of the era are registered in the height and width of the valley formations. The Champlain was eminently the Fluvial period of the earth's history, while *pluvially*, or as it respects rain, it may not have exceeded the present time.

This last section of my Memoir, which purported at the outset to treat of the amount of depression of the land during the melting of the glacier, has turned largely into a discussion of the evidences and effects of the Glacial flood—the subject of the first section. This is a consequence of the fact that the extent of the upper valley-terraces afford stronger testimony to the flood than the material of the beds, enabling us even to deduce the depth and spread and pitch of the flowing waters through the New England valleys, large and small.

In another paper I propose to present other facts on this and connected topics derived from Long Island and the associated lands off the Southern New England coast.

ART. LIII.—*Ammonia a constant contaminant of Sulphuric Acid;* by F. H. STORER, Professor of Agricultural Chemistry in Harvard University.

IN reflecting upon some of the reactions by which ammonia is known to be formed, it occurred to me that this substance would very probably, or perhaps necessarily, be produced in the ordinary process of making sulphuric acid, and that it might remain as a contamination in the acid as used in the chemical arts. Acting upon the idea I have myself tested and have caused to be tested carefully and methodically a considerable number of samples of sulphuric acid obtained from different chemical works, and have found that every one of the specimens examined contained appreciable quantities of ammonia. I find, moreover, on looking the matter up, that the observation is not new, inasmuch as Schœnbein* has stated, so long ago as 1862, that he found traces of ammonia in all the samples of oil of vitriol which he had tested for that substance. My experiments would nevertheless seem to be worthy of publication, both because they confirm Schœnbein's statement and because they go to show that ammonia is far more generally distributed as an impurity of chemical substances than has been commonly supposed hitherto.

The following acids were examined quantitatively by distilling a small portion of each of them with milk of lime, free from ammonia, and applying Nessler's reagent to the distillate, in the manner described by Wanklyn, in his "Water-Analysis," London, 1874.

I. Oil of vitriol from a carboy bought at Bay-Side Alkali Works, South Boston.

II. Oil of vitriol from the Chemical Works at North Billerica, Mass.

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* Wagner's Jahresbericht Chem. Technologie, viii, 266.

Finally, then, it appears that though we are justified, on grounds established by Helmholtz and Ericsson, in believing in the constancy of the heat-supply *within* the solar envelope for periods to come which are with reference to our terrestrial past almost infinite, we are not justified by our present investigations in asserting that the solar radiation has been constant during geologic periods, or is certain, or even likely to remain, what we now see it during corresponding periods in the future.

If there be great cyclical changes of long period (and in our present ignorance we can only say that such are not antecedently improbable) there will be corresponding changes in terrestrial temperature; and it is allowable to inquire whether we do not find here matter for consideration in connection with those great changes of temperature in past epochs which have in them nothing hypothetical, which geology assures us have indeed existed, and for whose possible cause no satisfactory suggestion has hitherto been made.

ART. LX.—*On Southern New England during the melting of the Great Glacier.—Supplement: The Overflows of the flooded Connecticut;* by JAMES D. DANA.

IN the remarks on the occurrence of Reindeer remains in the vicinity of New Haven, on page 356 of this volume, I have stated that the reindeers must have been living in the Quinnipiac valley after the retreat of the glacier and before the glacial flood; and on page 425 it is shown that the New Haven rivers must have had their floods from the melting glacier greatly prolonged by accessions derived from overflows of the Connecticut. It is evident that such overflows would have had an important influence on the geology of Southern New England, and I therefore present here the evidence I have been able to collect with regard to their positions and courses.

But, by way of introduction, I first mention some particulars from the older geological history of the great central valley of New England, since they serve to explain in part the occasion of these phenomena in its later history.

I. THE CONNECTICUT VALLEY BEFORE THE GLACIAL FLOOD.

It is well known that, in the Triassic period, and probably also the Jurassic, the Connecticut valley, from New Haven to Northern Massachusetts, was occupied by a brackish-water estuary—its length over 110 miles, its width for the most of the way 20 miles or more. Farther north, the valley for a long distance is narrow, and here the waters were probably those of a true river. The sides and bottom of the estuary were of crystalline rocks, similar to those outcropping over the bordering regions. The sand-flats and mud-beds that were made in the great estuary, out of the material contributed from either side by the rivers of the era, constitute its Red-sandstone formation.

The red sandstone of the area is now 300 feet above the sea-level near New Haven, and over 1300 in Massachusetts—a fact showing that, since Jurassic times, New England has been raised over its center at least a thousand feet more than along its southern coast.

With the exception of the seaward slope thus occasioned, and the erosion by denuding waters, the area of the Triassic sand-beds might have remained till now a wide plain, with the river of the valley flowing through it in a deep channel of its own making, and emptying into the Sound at New Haven, had it not been that the deposition of the beds was followed, over the whole area, by subterranean movements that ended in tilting them, making numberless long fractures to unknown depths, and filling the fissures so opened with melted rock. The sandstone was by this means left intersected by dikes of trap, along with adjoining hard-baked portions of its own beds which could stand wear a hundred fold better than other parts of the formation; and, as erosion went forward, the trap dikes became the trap ridges of the country, standing, with some of the enclosing indurated sandstone, as high barriers between different parts of the sandstone area.

A prominent line of these trap dikes divides the area, in a north-and-south direction, from Mount Tom (1214 feet high) near Northampton, Mass., to West Mountain (996 feet high) three miles northwest of Meriden; the valley is thus divided into an *eastern* and a *western* section, the former three times the widest. This range is called in the following pages, the Mount Tom Range, and also Divide Range.* This range is continued south of the Meriden hills in a low ridge of sandstone to Mount Carmel (736 feet high); then, by another lower ridge of sandstone to East Rock (360 feet high) nearly abreast of New Haven city.

For the convenience of the reader of this and other recent papers on New England geology, by the writer, a map of the

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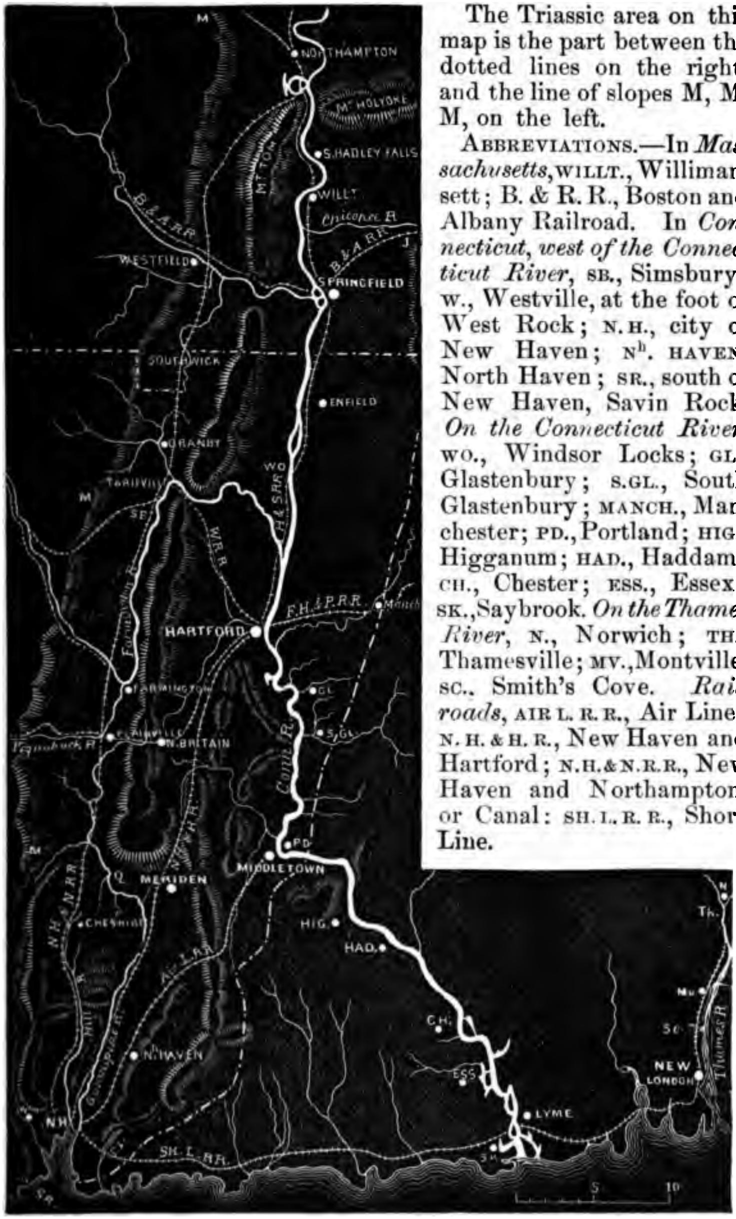
* This line of ridges from New Haven to Northampton was called the Mount Tom Range by President Timothy Dwight in 1796 (Travels, p. 5). Looking only at the general features of the country, he made this range a branch from the White Mountains; and the elevations of Western Connecticut, commencing at the West Rock trap range, near New Haven, he spoke of as a part of the Green Mountains. The error was not a bad one in 1796. But it has been reproduced since in geographies, encyclopedias and gazetteers, and recently it has appeared in a school book of Connecticut origin, and in a Guide book for the Connecticut Valley. It is alluded to here in order if possible to stop its further circulation. Over 50 years since, Professor Silliman corrected the error in this Journal, and yet it still survives.

MAP OF THE CONNECTICUT VALLEY AND PART OF THE COAST OF SOUTHERN NEW ENGLAND.



The Triassic area on this map is the part between the dotted lines on the right, and the line of slopes M, M, M, on the left.

ABBREVIATIONS.—In *Massachusetts*, WILLT., Willimansett; B. & R. R., Boston and Albany Railroad. In *Connecticut, west of the Connecticut River*, SB., Simsbury; W., Westville, at the foot of West Rock; N. H., city of New Haven; N^{h}. HAVEN, North Haven; SR., south of New Haven, Savin Rock. *On the Connecticut River*, WO., Windsor Locks; GL., Glastenbury; S.GL., South Glastenbury; MANCH., Manchester; PD., Portland; HIG., Higganum; HAD., Haddam; CH., Chester; ESS., Essex; SK., Saybrook. *On the Thames River*, N., Norwich; TH., Thamesville; MV., Montville; SC., Smith's Cove. *Railroads*, AIR L. R. R., Air Line; N. H. & H. R., New Haven and Hartford; N.H.&N.R.R., New Haven and Northampton, or Canal: SH. L. R. R., Shore Line.

Connecticut valley and part of Southern New England is here annexed.

These trap barriers naturally determined to a large extent the drainage-lines of the area. Since the eastern section is three times the widest, and the freest from dikes of the fire-made rock (trap), it is not strange that it became the course of the Connecticut River. But south of Hartford, between that city and Meriden, a succession of trap ridges rises to the east of this range, which crowd toward the river; and, consequently, the Connecticut, after passing Hartford, loses its westing; and then, at Middletown, where the metamorphic rocks are near in high elevations, turns abruptly out of its old valley through an opening heading southeast that then offered no doubt an unobstructed way to the Sound. Thus the southern part of the valley lost the Connecticut River. This event in New England history occurred before the Cretaceous period. After this, geology has no special facts from the valley until the Glacial period.

The western section of the sandstone area, shows that it was too contracted to become the course of the Connecticut by its subdivision into many river basins. The Northampton region is divided from the Westfield, and the Westfield from the Farmington. Moreover, the Farmington, while essentially one valley in its plains from Granby to New Haven, fifty miles, has three prominent rivers in this distance. Farmington river, the largest of them, makes a long V-shaped bend in the valley, first south and then north (as the map on p. 499 shows), and finally flows off into the Connecticut valley through a gap in the Divide Range near Tarifville. The eastern arm of the V lies in the broad flat meadows of the valley, with no ledge or hill to prevent the river's pushing southward instead of northward. In that same low plain, not two miles distant from the south end of the Farmington V, the Quinnipiac river becomes the river of the valley; but after flowing on for ten miles, this stream bends eastward out of it to the Meriden region, and then goes again southward, taking the way toward New Haven Bay that the Connecticut would have followed had it not been diverted southeastward at Middletown. Finally, where the Quinnipiac is deserting the valley, Mill River, the third of the streams, commences within the low Quinnipiac plain; and this stream holds its place in the valley to New Haven.

The facts here stated should be reviewed on the map in order that the remarks beyond, on the drainage in the time of the great flood, may be appreciated.

The Glacial period was one of extensive denudation throughout the valley, the ice working along with the subglacial waters; and the waters had unwonted denuding power, if the land was of higher level than now with the elevation increasing northward. The red sandstone of the valley is a soft rock, yielding easily to abrading agents; and through its removal the trap ridges of the valley may then have derived the larger part of their prominence. From the height above the Connecticut flats of the sandstone ridge called Mount Toby (or Mettawampe) in Sunderland, about thirteen miles north-northeast of Northampton, we learn that not less than 1200 feet of rock in depth has been removed from the sandstone formation of that part of the valley since the Jurassic period, of which a large part was probably the work of the Glacial era; and, on the same kind of evidence, that the removal near New Haven has exceeded 300 feet.

II. THE CONNECTICUT VALLEY DURING THE GLACIAL FLOOD.

In the next or Champlain period, when the land had subsided, and most deeply so to the northward, and when the melting of the glacier had far advanced, the valley was put under new conditions, as has been already explained; and, according to the evidence mentioned beyond, New Haven Bay was restored in part to its old rights by overflows giving it some of the surplus waters of the flooded Connecticut.

The height of the flood from the melting glacier as illustrated in the last number of this Journal, from the height of extensive terraces of stratified drift—was such that, at Middletown, the waters, instead of stopping at 24 or 25 feet above low-water mark, as now, continued rising until 175 feet deep; and from that level, they went plunging down the narrow channel to the Sound; that, at Hartford, the river rose above the modern 30-foot flood-level to 190 feet; that, at Springfield, they reached a height of more than 200 feet above low-water mark, and 240 feet above mean sea-level.

It admits of proof, further, that when the flood was at its height, the Connecticut overflowed in at least three places, westward, into the western section of the valley, and there flowed southward to New Haven Bay. These three places are—

First, over the Meriden divide, as has been already explained.

Second, at Westfield, west of Springfield, whence the waters descended along the western section of the valley, and finally joined Quinnipiac and Mill Rivers—New Haven streams.

Third, from the Northampton region, by the valley west of Mount Tom, over the Westfield divide to Westfield, there to join the Westfield overflow.

As to other westward overflows to the north I do not speak, as I have made there no special examinations.

The fact and the features of the western section of the valley have been long appreciated. So early as 1822 it was selected as the route for a canal from New Haven to Northampton, to be named the Farmington canal, which by 1835 was finished; and in 1847 the route of the unprofitable canal was taken for a railroad. called the New Haven & Northampton, or Canal, Railroad. Prof. Hitchcock, after an examination of a map and section of the canal, queried why the Connecticut river had not made for itself a channel along that route, rather than the more eastern; and in his "Surface Geology" he describes that section from Northampton to New Haven as a branch of his "second basin" of the Connecticut valley.

On page 140 of Prof. Hitchcock's first Geological Report of Massachusetts (8vo, 1835), and p. 329 of the second edition (4to, 1841), he has the following remark: "In tracing the Connecticut through this [its] valley the geologist will be surprised to find it crossing the greenstone ridge above described, and that too at its highest part, viz: through the gorge between Holyoke and Tom. For he will naturally inquire: Why did not the river flow through the valley *west* of the ridge, and, following the course of the Farmington Canal, empty at New Haven? for it appears from the surveys on this canal, that in no place is that portion of the valley more than 134 feet * above the present level of the Connecticut at Northampton, whereas the trap ridge through which it passes is from 800 to 1,000 feet high.

The denudation required for "crossing the greenstone [trap] ridge" appears less difficult when the fact is recognized that Mt. Tom and Mt. Holyoke are two independent trap-dikes of very different trends, the latter an east-and-west dike; and that, as is seen at the eastern foot of Mt. Tom, along the river, there was sandstone between them; so that it was sandstone that was removed for the river or by the waters of the valley, and not trap.†

Prof. Hitchcock says, in his Surface Geology (1857), speaking of the topographical basins into which the Connecticut Valley may be divided (p. 11): "The second basin extends from Holyoke to Mettawampe (Mt. Toby) in Sunderland and Sugarloaf in Deerfield. From Holyoke this basin must have extended southerly along the *west* side of Mt. Tom and the other trap ranges that extend almost continuously to New Haven. Through this valley runs the Canal Railroad, but nowhere is this valley more than 134 feet above the Connecticut at Northampton, and this is not so high as some of the terraces."

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* The survey for the Canal found the greatest height two miles north of Westfield, between Westfield and Northampton, and made the height of the top of the divide above the level at Northampton, 86 feet, and the height of the latter above the Connecticut River 48 feet; and 86 + 48 = 134.

† Dr. Percival, in his Report on the Geology of Connecticut, brought out the fact that the trap ridges of the Triassic area are often made up of two or more trap-dikes separated by sandstone; that is, are formed from the fillings of two or more independent fractures—independent at least at surface. Pine Rock, a trap ridge east-northeast in trend (like Mt. Holyoke) in the New Haven region (P on the map of p. 415), appears as if it were a continuation of the south end of West Rock, which turns toward it, and still they are wholly distinct; and Pine Rock, although not half a mile long, is actually a combination of four masses or dikes of trap with sandstone between, and a third of the length is sandstone. Again, East Rock (E, on the same map) consists of three dikes with intervening sandstone. It is owing to this composite character that gaps through the high trap-ridges are not uncommon. The associated sandstone, while generally hard-baked, is sometimes cracked into small chips as a consequence apparently of too *dry* heat in the baking.

The idea here conveyed is expressed also on the map of the Connecticut Valley, forming plate III, of the same volume. A terrace-plain, numbered 2, is made to spread southward from Northampton, or rather from Greenfield more than twenty miles north of Northampton, through Southampton, Westfield and Southwick in Massachusetts, and Granby in Connecticut. The map, however, presents a suggestion of the author's mind rather than a fact at the time established: for terrace No. 2 of Northampton, the highest mentioned for that place, is according to the text, only 97 feet above low water in the river instead of 134 feet, which makes it nearly 40 feet too low to pass over the divide to Westfield.*

Further, it is necessary to note, in order to apprehend Prof. Hitchcock's views, that in discussing the origin of terraces in the same work (p. 49 and beyond) he makes the ocean a chief agent in producing "beaches and terraces," and supposes a submergence of the land of 2,000 to 2,500 feet (pp. 53, 54), attributing part of the effects to icebergs, marine erosion, and the making of seashore beaches and flats during the period of submergence and during a progressing emergence, and part to the drainage which was again set in action by the emergence. In his Geological Report (1841) he makes the terraces a result of river erosion. The terraces of the Connecticut Valley, in the view I have presented, are wholly of fluvial origin, and the highest terraces of the various valleys, whether over the lower or higher parts of the country, are approximately measures of the flood-level in each.

The proof with regard to these westward overflows is derived from the terraces of stratified drift over the regions.

1. *Overflow at the Meriden divide.*—On this overflow it is necessary here only to repeat in brief the facts from page 425

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* The numbers affixed to terraces by Prof. Hitchcock, in his Surface Geology, express the succession at a locality, beginning with the lowest as No. 1: so that terraces of different localities that are the same in height have often different numbers. The Northampton region has only two terraces, numbered 1 and 2, respectively 57 and 97 feet above low water in the Connecticut, and the latter stated to be 202 feet above the sea-level. At Whately, half a dozen miles north, there are three, Nos. 1, 2, 3, respectively 32, 46 and 92 feet in height, the last 206 feet above the sea-level, and therefore the same with No. 2 of Northampton; yet this No. 3 has a different color on the colored map. No. 2 at Greenfield, a dozen miles farther north, is 291 feet above the sea-level, and therefore different from either of those at Whately or Northampton. This feature of the work has to be noted in order rightly to apprehend the facts it presents.

Prof. Hitchcock also has "moraine terraces" and "sea beaches", among the phenomena of high levels over the country—which I have been led to regard as mostly terrace-formations at high levels where there were water-courses during the era of the melting glacier, if not so now.

of this volume: that the divide 1½ to 2 miles north of Meriden, is on the borders of the Hartford river-region: that the highest part of the divide is near the Hartford flood-level, about 160 feet above modern high water in the river; and that over 20 feet of terrace sands and gravel, that is, stratified drift, underlies the summit plain. The red sandstone outcrops in some places over the top and rises into ledges. The overflowing waters eroded the sandstone surface, and descended to the Quinnipiac, just below Meriden, to swell the stream and increase the height of its terrace depositions.

2. *Overflow from Westfield, Mass., over the Southwick divide, into the Farmington Valley.*—The village of Westfield is situated nine miles west of Springfield, on Westfield River, a large and rapidly flowing stream tributary to the Connecticut. The river emerges from its confined valley of metamorphic rocks, about twelve miles west of the Connecticut River, at "Mt. Tekoa," and there enters the open Red-sandstone area in which Westfield is situated. Five to six miles west of the Connecticut, it passes through a gap in the Mt. Tom or Divide Range, and enters the present Connecticut Valley. The Westfield region is hemmed in on the north by the Westfield divide, between it and Northampton, and on the south by the Southwick divide, separating it from the Farmington Valley—both made of red sandstone, but having, over the sandstone, levelled deposits of stratified drift.

The upper terrace of the region extends from the city of Westfield three miles westward.[*] The material is sand and gravel, as usual—with the gravel, at the section I examined in the city, constituting the upper 25 feet, excepting 2 or 3 feet of sand at top. According to a levelling by Mr. H. F. Dunham (assistant to Mr. G. A. Ellis, of Springfield,) the height near its eastern limit is about 239 feet above mean sea-level; and from this it gradually rises westward—or up stream—to 286½ feet. The 239-foot level is very near that of the highest flood about Springfield (240–245 feet); it is about 96 feet above modern flood-level in Westfield River.

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[*] See a colored map of the Westfield terraces in Hitchcock's Surface Geology, Plate VII. The author expresses his doubts with regard to the heights he gives. His No. 4 corresponds nearly with the lower part of the upper terrace as measured by Mr. Dunham. The region along the course of the old Farmington canal, from New Haven to Northampton, was surveyed for the canal-route by Mr. H. Farnam, then Assistant Engineer, and in charge of the work. The section published on a map engraved by Messrs. N. & S. S. Jocelyn, of New Haven, in 1828, gives all the lockage to Northampton, and, in fact, beyond this to White River Junction, its projected termination. The section makes the water level of the canal over the Southwick divide, through the Southwick Ponds, 220 feet above mean sea-level; at Westfield, alongside of the present Railroad Station, and nearly on a level with the track, 144·75 feet; over the Westfield divide, 230·75 feet; at Northampton, 48 feet above its termination at water-level in the Connecticut, 144·75 feet. Mr. Farnam informs me that the plain of the Southwick divide was as I had estimated, about 20 feet above the level of the Ponds, and thence about 240 feet above mean sea-level; that of the Westfield divide, about 10 feet above the level of the canal, or 241 feet. As bearing on these levels I state further that according to the surveys of the Connecticut River, under Gen. T. G. Ellis, the height of the railroad track at the Springfield Station is about 70·4 feet above mean sea-level. Mr. H. F. Dunham, assistant in the office of the City Engineer, Springfield, obtained, in a careful levelling from Springfield (obligingly made for this place), 148·84 feet for the level of the track (top of rail) at the Westfield Station. He judged that the water-surface of the canal was probably 2½ feet below the same level. By adding 53 feet (from R. R. levelling) to 70·4 gives 123·4 for the height of the track at the Northampton station. But according to Mr. E. C. Davis, Civil Engineer in Northampton, the track there is about 19·7 feet below the level of the old canal.

The proof that the waters of the flood passed the Southwick divide into the Farmington Valley is as follows:

1. The upper terrace plain of the divide is not above the height of the upper terrace plain of the Westfield region.

2. The Southwick Ponds, which lie along the lowest part of the divide, where it was passed by the Farmington Canal, are lower than the lower level of the upper Westfield plain.

3. The terrace plain of the divide may be followed down the Farmington Valley.

On the 1st and 2d of these points I observe that the height of the Southwick Ponds is about 78 feet above high water in Westfield River, or 220 feet above mean high tide—which is nearly 20 feet below the lower part of the upper Westfield terrace. A terrace bordering the ponds carries the height up to about 240 feet. The level rises to the northwest over the Southwick plain: but there, along the railroad track, the height is but 260 feet, which is 25 lower than the higher part of the Westfield terrace.

We may hence conclude that before the flood exceeded in height 220 feet, the flow southward had begun; and that as the waters rose the terrace deposits above that level were laid down over the divide. Since 240 feet was also the height of the highest terrace on the Connecticut east of Westfield, the waters of the overflow may have been in part those of the Connecticut; but it is probable that they were solely from Westfield River—waters which the Connecticut was thus deprived of; for the height of the flood over the middle of the Westfield basin was at least 275 feet, as shown below, the waters having been held up to this level (30 feet above their height at Springfield) in consequence, probably, of the narrow passage for them below Westfield through the Divide Range.

As to the third point, I give the following table of heights of the upper terrace along the valley south of the divide—the terrace plain in each case, the first excepted, being extensive.*

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* The terrace at Tarifville rises at first abrubtly, near the railroad station, and afterward with a slope which extends beyond the cemetery; the deposits are of fine earth, excepting the upper 20 feet which are pebbly. The top is not clearly defined, but appears to be indicated by the pebbly beds. The Simsbury terrace is an elevated plain, directly west of the railroad. There is an extensive plain about

	Distance south of the Divide.	Height above flood-level.	Height above mean sea-level.
Tarifville	8½ miles.	115 feet.	275 feet.
Simsbury	12 “	110 “	270 “
Farmington Station	22 “	80 “	254 “
Plainville	26 “	49 “	234 “
Southington	30½ “	75 “	223 “

The facts show that the flood had a height over the Southwick divide of at least 270 feet; that this level was kept up as far south as Tarifville and Simsbury by the inflow of the flooded Farmington; that south of Simsbury the decline in height was very gradual; and that even at Plainville, where the flat valley spreads to a great width, the terrace was made to a height but little lower than the plain at the divide. At Tarifville, the Farmington is reached and here the waters from Westfield joined those of that river.

The high level at Tarifville and Simsbury is very remarkable, considering the open cut through the Divide Range by which the stream now enters the Connecticut valley, and the fact that the terrace-plain east of the range is full 50 feet lower than that west. But the cut is not 100 yards wide; and, besides, it may have been filled with drift from the glacier (as was the Niagara channel), and the removal of the obstruction have not begun until the flood had reached its height.

Reaching Plainville, the waters left the present Farmington River area, to enter the Quinnipiac; for there was nothing to prevent, all being one plain below; and a Farmington valley terrace 49 feet high continues southward as the terrace of the Quinnipiac. Thence they went down the Quinnipiac Valley to New Haven Bay.

Where the Quinnipiac River, ten miles from its source, below Southington, commences to bend out of the valley, part of the waters joined Mill River—no impediment existing there in hills or ridges; and the upper terrace of the Quinnipiac continuing on down Mill River.

Thus the flooded Farmington, swollen still farther by waters from the Westfield overflow, occupied the whole Farmington Valley from the Southwick divide to the Sound; and the flood discharged into New Haven Bay by two of its streams, Quinnipiac and Mill Rivers.

It is a misfortune to the State of Connecticut that the Farmington River did not take advantage of the opportunity thus afforded to dig a channel deep enough to ensure its permanent flow to New Haven; since, with such a river, the bay would have made one of the best harbors on the New England coast.

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the Granby Station at about 210 feet above mean sea-level. The terrace measured at Plainville is on the east side of the Farmington Valley, 1½ m. from the railroad station, close by the Quinnipiac. I am indebted to Mr. H. F. Root, Civil Engineer on the Canal Railroad, for heights along the road.

3. *Overflow from the region of Northampton, by the west side of Mount Tom, to Westfield, to join the flow down the Farmington Valley.*—The obstacle here was the divide north of Westfield.

The upper terrace of the Northampton region is one of the best defined terrace-plains of the Connecticut valley. It is only two miles west of Northampton, and is known as the Florence plain, part of it being the site of a village of that name. Its height above mean sea-level, according to the survey for supplying the city with water, as I am informed by Mr. E. C. Davis, Civil Engineer, is 260 to 265 feet. The terrace which Prof. Hitchcock gives as the highest in northern Northampton occurs also just west of the city, though with the surface rising westward; its height he gives as 97 feet above low water, and 202 above tide level; and it is therefore 60 feet below the level of the Florence plain.

The Florence-plain level, 260–265 feet, is evidently a northward continuation of the upper Springfield level, that of 240–245 feet. There is hence a difference of level of 20 feet in a distance of 16 miles. But if the land were depressed, with the depression increasing northward at the rate of a foot a mile, the pitch would have been slight. How far the narrows between Holyoke and Tom affected the height of flood-level above and below, I have not investigated.

From the height of the upper terrace-plain at Northampton, we know that the flood-height there was *not below* 265 feet; and probably it was 10 or 15 feet above this, as Hitchcock mentions a terrace of 289 feet near Hadley. What then was the level of the Westfield divide?

This divide at its lowest part, where it was crossed by the Farmington canal, has a height of but 241 feet above mean sea-level, which is more than 20 feet below the terrace-level at Northampton. We have good evidence, therefore, that the overflow took place, and that the stratified drift of the divide owes to it its deposition. High terraces exist along the sides of the valley between the divide and Northampton.

Passing the divide the waters joined those of the flooded Westfield River; and if so, they became part of the overflow which descended by the Farmington, Quinnipiac and Mill River valleys to New Haven and the Sound.

Conclusions.—(1.) The Connecticut when the Glacial flood was at its height had a depth of 150 feet, or more, all the way from Middletown to Turner's Falls at Springfield—and to an undetermined distance beyond; and from Hartford to Turner's Falls it averaged fifteen miles in width. It was a great stream, fed by numerous headlong torrents from either side; and, at the same time, feeding other streams from its surplus waters. Its depth and extent was in spite of great losses from overflows into other valleys.

(2.) The violence of the flood in the Connecticut valley was confined mostly to the time of its maximum height. At Hartford, Springfield, Westfield, and elsewhere, the coarse deposits have been found to be those of the upper portion of the terraces; not of the upper terrace alone, but often also of the lower, and because the low may be of flood-origin as well as the highest. (This volume, p. 178.) When the Connecticut flood at Springfield was about 120 feet above modern flood-level, or 180 feet above mean sea-level, and at corresponding height northward to Northampton, the waters were sluggish; for clay beds, which could be formed only in sluggish waters, are common through the region up to this level; and with the clays, except at points remote from the river, there are only fine sands—other evidence of the absence of all violence of movement. For the next 20 feet the beds at Springfield continue to be of sand. The cause of such an almost lake-like condition over this region, when the waters were already so high, can be explained only by assumptions, and for the present I let them pass unconsidered. Above the 200-foot level at Springfield, the deposits are generally coarse.

(3.) The facts show that the flood of the New Haven rivers did not cease when the melting glacier had disappeared from their valleys, even if so to their very sources. While the glacier was continuing its retreat to the Massachusetts border, the Farmington River may have been pouring its floods down the Quinnipiac; and during the long retreat through Massachusetts and the States north, both the Quinnipiac and Mill Rivers were swollen with waters from the overflowing Connecticut.

Such conditions have to be taken into consideration in order to study rightly the Quaternary geology of the country, or of any Glacial land. The reindeer bones in the clay beds of the Quinnipiac (this volume, p. 353) indicated, by their position and freedom from wear, that reindeers lived in the valley after the retreat of the glacier and before the glacial flood had reached its height; and we may understand from the above observations how and why this was possible. The conditions of all the rivers of the ice-covered land when at flood height, their depths, widths and overflows, must be worked out and mapped, before the events of the Fluvial or Champlain period in the Earth's history can be fully understood or appreciated.

Correction for page 427.—The narrows below Middletown are 650 feet wide at low water and 800 at extreme high, according to Gen Ellis (Rep. U. S. Engineer Dept. for 1859), who thus explains the height of the modern floods above.

Des Cloizeanx on the optical properties of the Feldspars, p. 480.—The following errors occur in this article. In lines 3 and 20 from foot of page, 19° 27′ for 15° 27′, and in the bottom line, 7° 12′ for 5° 12′.

Watson's Descriptive Geometry.—The work noticed on page 488 is by Wm. Watson.

[FROM THE AMERICAN JOURNAL OF SCIENCE AND ARTS, VOL. XII, AUGUST, 1876.]

ON SOUTHERN NEW ENGLAND DURING THE MELTING OF THE GREAT GLACIER.*

BY JAMES D. DANA.

APPENDIX: *On the discharge of the flooded Mill River into the Quinnipiac, and the effects as registered in the drift deposits of the New Haven plain.*

IN my memoir on "Southern New England during the melting of the great Glacier," I reached the conclusion† that, during the Champlain period, or that which opened with the melting of the ice, the southern coast of New England, along Long Island Sound, was submerged below its present level not more than fifteen feet, and perhaps less than ten. It was announced,‡ as a consequence of this fact, that the high terraces of stratified drift about the heads of the estuaries and along the river valleys could not have been made by salt water, and must have been due to the freshwaters of the enormously

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[*] The former parts of this memoir are contained in this Journal, III, x, 168, 280, 353, 409, 497, and xi, 178.

[†] Ibid., x, 434.

[‡] Ibid., x, 435.

flooded streams; and that all the drift-deposits of the New Haven region, now thirty to fifty feet above mean tide, were included in the freshwater formations—the saltwater beds being confined to the coast.

The New Haven deposits had been described* as having, to a great extent, a cross-laminated structure, with the oblique lamination dipping for the most part seaward; and hence it was evident—contrary to what I had once supposed—that this dip corresponded in direction with the flow, both being seaward. My former conclusion on this point was based on the view that the New Haven estuary beds were marine in origin; and this appeared to be sustained by the fact† that in the stratified drift beds at the mouth of the Quinnipiac Valley (or where the valley expands into the New Haven plain, west of C on the map, p. 415 of vol. x), the *upper* stratum, twenty feet thick, had the cross-lamination dipping landward, and the *underlying* stratum seaward; for the change of current indicated by this local change of dip seemed to be accounted for by supposing the lower stratum to have been made by the incoming tide, and the upper by the outflowing stream when the flood was at its height. I closed my memoir by rejecting this explanation of the change of current, but without offering any other in its place.

My object at this time is to give another explanation; and to show that while the Quinnipiac waters deposited the lower stratum, the upper was formed by a discharge of Mill River into the Quinnipiac over the place where the unlike strata occur.

As has been explained (and is illustrated on the map, page 415 of volume x), Mill River and the Quinnipiac are parallel streams, joining their waters at the head of New Haven Bay. For the last nine miles of their courses they are less than three miles apart; and the low dividing ridge (Quinnipiac Ridge of the map) terminates near New Haven in the short trap and sandstone ridge called East Rock (E, on the map). Below this termination no barrier intervenes excepting a plain of drift deposits, and here is the place where the upper stratum of twenty feet has the reversed cross-bedding. Now if it can be shown that Mill River was throughout its course a violent cataract, flowing at a level far above that of the Quinnipiac, while the Quinnipiac for the last six miles had almost no descent, and was in this part more like a lake or basin than a river, it will be plain that Mill River, on clearing the south extremity of the East Rock ridge, would have rushed around the point, toward the Quinnipiac.

The facts sustaining this view have already been stated in my former papers.* At North Haven, or six miles north of New Haven, the Quinnipiac River is now on a level with the ocean, while Mill River in the same latitude is sixty feet above it. The valley-terrace of stratified drift is, in each valley, about forty-five feet in height above the stream. Consequently, in the Champlain period the descent, from that point to Long Island Sound, of Mill River was 105 feet, and of the Quinnipiac, only forty-five feet. Moreover, the Quinnipiac terrace has nearly the same height at North Haven and five miles south; so that the waters over this broad area during the Champlain flood were nearly those of a great basin. But, abreast of this long Quinnipiac basin, the Mill River torrent was dashing on with a pitch of ten feet a mile. And it continued this rapid plunging course along its shallow valley until it had passed East Rock, where the valley terrace is seven feet higher than that of the Quinnipiac adjoining. It is therefore manifest that, on reaching the southern extremity of the ridge separating the two valleys, it would have made a quick turn around the promontory and plunged into the Quinnipiac basin; and this would have carried it northeastward directly over the place where the evidences of reversed currents occur in the drift deposits. This place of discharge would not have taken off all the Mill River waters, or the larger part; for the water level there, when the flood was at its height, was still thirty to thirty-five feet above the sea-level—height enough to have kept the tumultuous waters mainly on a seaward course.

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* Ibid., x, 191.

† Ibid., x, 173.

We hence learn from the drift deposits at this place of junction of the two streams, southeast of East Rock, (a mile north of the present head of New Haven Bay and six miles from its eastern cape), the following facts:

1. Until the waters of the flooded streams had reached, at the place mentioned, a height of fifteen feet above the then-existing sea-level, neither stream overbalanced the other; for the deposits of the lower stratum within the range of the Quinnipiac valley show, by their structure, that they were made by the flow of Quinnipiac waters. The pitch of the waters to the Sound was then but two or two and a half feet a mile.

2. Until the same water-level was reached, the flow—though rapid and plunging, as proved by the flow-and-plunge structure of the beds—was quiet compared with what followed; for this lower stratum consists mainly of sand and fine pebbles.

3. The increase in the flood on passing that level was sudden, as if the dissolution of the glacier had then received greatly accelerated progress. For the transition in the bedding, and in the color of the sands, is abrupt, with no fine layer between to indicate an epoch of repose; and, moreover, the *upper* stratum is

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* Ibid., x, 413.

very much the coarsest; along Mill River valley, it is to a great extent, in contrast with the stratum it overlies, a cobble stone deposit, and this evidence of hurrying waters continues along its course through the New Haven plain for a mile and a half to the Bay.* Further, the height of the deposits where the stones are coarsest is ten feet below the normal height, because in the dashing flood, the finer material was drifted off.

4. The flow from Mill River into the Quinnipiac basin diminished in velocity as the waters spread in that direction. For, while the upper stratum adjoining Mill River on the east is a mass of coarse pebbles, too stony to show any cross-bedding, going farther eastward, toward the Quinnipiac, the stony character diminishes, and finally, in the course of three-fourths of a mile, the beds consist largely of sand.

5. The great plain of stratified drift, southeast of East Rock, forty to forty-three feet in height above the sea-level, which bounds the Quinnipiac salt meadows on the south and pushes the river against the eastern hills, was made largely of sands contributed by the Mill River torrent.

6. The Quinnipiac waters added little to the height of this drift-deposit plain or terrace: for the upper stratum bears evidence of Mill River action nearly or quite to its top. There are over the top some areas of whitish sand, one to three or four feet thick; and a bank of such sand, finely and evenly bedded, lies, unconformably against the slope of stratified drift facing the Quinnipiac basin; † and these may be formations from the Quinnipiac waters after the Mill River floods had subsided.

7. Mill River—now not over fifteen miles in length—is an example of a little stream that was a great river during the Glacial flood. It owes this partly to its having been one of the water-courses that aided, as I have pointed out,‡ in discharging the flooded Connecticut—the overflow at Northampton and Westfield giving a vast supply of waters to the Farmington Valley, enough to fill the wide valley over a hundred feet in depth, and forcing them to find a discharge into Long Island Sound by the Quinnipiac and Mill Rivers. It was probably through this supply of waters from the Connecticut that the floods of Mill River were prolonged until the drift deposits of the New Haven plain had reached their extreme height.

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* Ibid., x, 175.

† Ibid., x, 179, 180, where a figure is given. The origin of these beds is otherwise explained at that place, the error that the estuary beds were marine, coloring much of the reasoning in that first paper on "Southern New England."

‡ Ibid., x, 506.

[From the American Journal of Science and Arts, Vol. XI, Feb., 1876.]

Green Mountains.—On page 498 of the last volume of this Journal (Supplementary December number), a note is inserted corecting the blunders which have long circulated in Geographies, Gazetteers, Encyclopedias, and New England Guide-books, as to he Green and White Mountains terminating in trap ridges—alled West and East Rocks—in the vicinity of New Haven; the act being that East Rock is but a short appendage (half a mile ong) to the system of trap dikes of the Connecticut valley, and West Rock, a southern portion of the same system. Prof. O. P. Hubbard has informed the writer that this extraordinary error in New England Geography has the following forms in "The Imperial Gazetteer" published by Blackie & Son at Glasgow, Edinburgh and London, in 1855. Under New Haven, "Surrounded on hree sides by spurs of the Green Mountains." Under Green Mountains, "A mountain range commencing near New Haven, Connecticut." Under Connecticut, "Some of its mountains, particularly the Green Mountain range," etc.

The Green Mountains consist of metamorphic rocks and are not younger than Silurian. They have their greatest height in Vermont, and there received the name. The mountain system extends south through *western* Massachusetts and *western* Connecticut, and the whole is rightly called the Green Mountain chain. But the trap ridges of the Connecticut valley, belong to the valley, and are of Jurassic origin. J. D. D.

valley, had been closed by drift and so remained until the flood had reached its height.

I allude to this subject again to add that the events connected with the opening, in the Spring, of many of our modern ice-covered streams afford abundant reason for believing that, during the breaking up of the long Glacial winter, when the melting was going forward, the gaps, gorges or narrows, along the river courses, would have been liable to obstruction by floating ice.

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* Ibid., x, 175.

† Ibid., x, 179, 180, where a figure is given. The origin of these beds is otherwise explained at that place, the error that the estuary beds were marine, coloring much of the reasoning in that first paper on "Southern New England."

‡ Ibid., x, 506.

[From the American Journal of Science and Arts, Vol. XI, March, 1876.]

ON THE DAMMING OF STREAMS BY DRIFT ICE DURING THE MELTING OF THE GREAT GLACIER.

By. J. D. DANA.

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When treating of the overflows of the flooded Connecticut, in the Supplementary December Number of this Journal, (p. 497,) I suggested, in view of the fact that the terraces in the Farmington Valley about Tarifville and Simsbury are at least 50 feet higher than those a mile eastward in the parallel Connecticut valley—that the gorge through the Divide Range, by which the Farmington river there passes into the Connecticut valley, had been closed by drift and so remained until the flood had reached its height.

I allude to this subject again to add that the events connected with the opening, in the Spring, of many of our modern ice-covered streams afford abundant reason for believing that, during the breaking up of the long Glacial winter, when the melting was going forward, the gaps, gorges or narrows, along the river courses, would have been liable to obstruction by floating ice.

(*a*) Such obstructions would have been of all grades, from that which could simply impede the free flow of the waters, to the nearly perfect dam.

(*b*) The obstructions in particular cases might have existed for a very long era, instead of for a few weeks such as happens after a modern winter.

(*c*) Again, the slackened or suspended flow of the water, caused by such ice-obstructions, would have favored the deposition and accumulation about them of drift, and some may have thus been converted into complete dams. This process might occasionally have wholly filled with earthy material a gorge or narrow valley, so as to block up and divert the course of the stream.—The well-known case of Niagara River may be an example of this.

In view of these possible results, or rather these probable conditions of many river-valleys in the era of the Glacial flood, we are required to consider whether the height of the upper terraces *above the narrows* on the several rivers,—the Thames below Norwich, the Connecticut below Middletown, the Housatonic below Derby, Westfield River below Westfield, and Farmington River east of Tarifville—was not partly owing, in each case, to the existence of ice-obstructions at the narrows.

It seems to be very probable that this was so. The height of modern spring floods in the Connecticut at Middletown and Hartford is now often due in part to this very cause.

It appears to be certain, that if such obstructions existed in the Thames, Connecticut and Housatonic valleys, they were only partial obstructions; for, in the case of each, the terrace of the valley below the narrows *declines quite gradually in height* from the level above the narrows, instead of abruptly. Had the waters been held back, up to the height of the high upper terrace, by a close dam, they would have fallen over the dam with a plunge to a lower level; and this abrupt fall would have been registered by means of an abrupt fall in the level of the terrace. Instead of this, the terrrace on passing the narrows southward falls off at a rate not exceeding 10 feet a mile, varying in rate only with the varying width of the valley: a fact that seems to testify to the vastness of the flood as its cause, and not mainly to obstructions. Moreover, the material of the terraces below the narrows is like that above: the same in the prevalence of sands below and coarse gravel at top,—though having the latter of greater coarseness because of the more rapid flow of the stream along a narrower valley.

Further evidence with reference to the existence of such ice-barriers is to be looked for in a distribution of gravel and large bowlders across the valley just above the gorge or narrows, where the ice-masses had been brought to a stop and piled together;

for much of the floating ice would have been loaded with bowlders. I have as yet observed no satisfactory evidence of this kind, but think the question needs more investigation. Even if this evidence fails, we can hardly assert that no aid was afforded by ice in producing the great height of the flood-waters above the narrows, or doubt that ice-barriers made of drift ice had much to do with the height and extent of the upper terraces in portions of many other valleys.

There are two questions which should have here a word.

1. *May not the obstructions or dams have been made by the Glacier itself?* On this point we observe that the extent of the terrace formations along the valleys,—sometimes a score of miles in width even in New England—show that water swept in immense streams over the surface; and thus they seem to prove that the glacier was already out of the lower part of the valleys, and hence too far away to have obstructed the flow except through the pieces set afloat by its dissolution.

2. *Were not the dams due to rocky barriers at the narrows, or to the non-excavation of the valley from the narrows southward?* The features of the region about the narrows on each of the rivers mentioned, and of the valleys below, suggest decidedly that the valleys had nearly the same depth and extent then as now. The gradual decline in the height of the terrace on going from the narrows southward to the Sound shows that all was one valley, the part above the narrows and its continuation below. The terraces below the narrows, moreover, are built up in general from the *present* bottom of the valley, or from a lower depth, and this points to a depth for the valley as great as now or greater. It cannot be urged that the lower portions of the terraces were made after the upper. Wherever the hills on one side, at the narrows, retreat so as to give a chance for high terrace deposits, there these deposits are usually found, and sometimes the beds rise abruptly from the water's edge to the level of the highest terrace; and on the Connecticut, in a place of this kind above Middle Haddam, the bottom layers are of clay—like the lower layers in much of the stratified drift on the river.

In fact, the conditions of the terrace deposits of the valley, as well as the features of the valley itself, are explicable only on the view that the part of each valley below the narrows, like the rest of it, the narrows included, had been made before the Champlain period opened. The Glacial period was the era of valley excavation rather than the Champlain period.

[FROM THE AMERICAN JOURNAL OF SCIENCE AND ARTS, VOL. XIII, JAN., 1877.]

On the Glacial Phenomena of North America; by Professor OTTO TORELL, of Sweden. (Proc. Amer. Assoc., Buffalo.)—The following is a report of the paper by Professor Torell in the New York Times of August 30.—It may be assumed that the circumstances essential to the formation and movement of glaciers are these: 1. Abundance of moisture in the atmosphere; 2. A low temperature, due either to great elevations in low latitudes, or to high latitudes with or without such elevations of land. These conditions insure such accumulations of snow above the line of perpetual frost as will sooner or later pass the line of perpetual snow and be changed to ice and water. The water becomes glacial rivers, and the ice will move as a plastic mass to a line determined by the amount of snow, on the one hand, and the climate on the other. The advancing movement of the glacier is accompanied by erosion and scratching of the rocks below and by the different kinds of moraines, as till or blue bowlder clay, and yellow unstratified masses—terminal, lateral, and superficial moraines. Simultaneous with these phenomena we have this action of the glacial river, namely, a partial denudation of the moraines, and the formation of stratified gravel, sand, and clay.

The glacial phenomena of the Glacial period were as follows: 1. The sinking of the temperature, accompanied by the formation and increase of glaciers; 2. The motion of the ice to its extreme limit; 3. The formation of moraines, of which a part were moved forward and constituted terminal moraines, while another portion was passed over by the ice, and then became bottom or ground moraines; 4. The removal by this advancing glacier of the glacial river deposits, or the covering of them by the glacier itself and its ground moraine. A geological section of the edge of the ice would then present either (*a*) preglacial beds; (*b*) stratified glacial deposits; (*c*) a ground moraine; (*d*) the ice with its terminal moraine: or (*a*) scratched rocks; (*c*) a ground moraine; (*d*) ice and terminal moraines. The first-named section is most common in the portions of Europe covered by Scandinavian erratics. The second is found generally in Scandinavia and in the United States.

The retrograde movement of a glacier during the period of melting is characterized: 1. By the formations of upper or terminal moraines, which are more or less leveled by local backward and forward movements of a glacier during successive intervals of time; 2. By stratified river deposits lying upon the unstratified yellow moraine, so that a section above the sections just described will present (*a*) preglacial beds; (*b*) stratified deposits; (*c*) till or ground moraine; (*d*) terminal moraines leveled down to great fields containing unstratified materials; (*e*) stratified beds formed by glacial rivers with gradually descending sources. The characteristics of deposits (*b*) are that only in the vicinity of high mountains they contain rounded stones, while farther away they consist of deposits of sand and clay. The characteristics of the deposits (*c*) are: A blue color, due to the seclusion from the oxidizing action of the air; compactness and hardness; rounded form of the bowlders, which are polished and scratched, and also generally brought from remote places. The characteristics of the deposits (*d*) are: A yellow and reddish color, occasioned by peroxidation of iron, comparative looseness of the mass, and greater angularity of the bowlders, which are rarely scratched, and usually belong to neighboring localities. The characteristics of the deposits (*e*) are: Stratification, abundance of rounded and unscratched bowlders; they generally consist of beds of gravel and sand, without clay. These phenomena are found not only in Europe wherever there are traces of the ice age, but are observable in the United States and in the region to the north of them. Each glacier has had its own limited area, and the same appears to have been the case with all the great drift deposits in North America. The greatest ice-field of Europe was that which originated in the highlands of Scandinavia, and thence extended over those portions of Northern Europe which are known to be covered by Scandinavian erratics.

By investigations extending through a long period of years, I have found that the above-mentioned glacial beds or deposits exist in all the countries above indicated. The Scandinavian glacier crossed the Baltic and German Ocean, and extended its moraines into the suburbs of London on the west, to the slopes of the Riesengebirge in the southeast, to the Tjernaye Bay, the icy, on the northeast. The presence of precisely similar phenomena in North America has established in the minds of a majority of geologists the conviction that a vast area over which such phenomena are found has also been covered with ice. But if we carefully examine this region it will readily appear that the glacial area is not continuous from ocean to ocean, but it is divisible into a northwestern area, and the Rocky Mountain area and others to the west, separated by a broad, driftless belt extending from the base of the Rocky Mountains nearly to the Mississippi, thus forcing the conclusion that the great Eastern and Western ice-fields have had different sources.

It has been the opinion of many distinguished American geologists that the source of the eastern ice-fields is to be sought in the Canadian highlands. Against this opinion several important reasons may be urged. First, in the portions of Canada in which the glaciers in question are supposed to have originated, we have reason to believe that the rocks are rounded and scratched, phenomena everywhere recognized as glacial; but I think in no case characterizing rocks known to have been covered with perpetual snow. Again, the elevation and extent of the highest portions of Canada are hardly sufficient to account for the requisite accumulation of snow and ice. And finally, so far as I have learned, there is not formed upon the rocks of the northern slope of Canada, nor yet in bowlders moved by glacial force, any satisfactory evidence that there had been a northward as well as southward movement of glaciers from the highlands of Canada.

If, therefore, the phenomenon of the northern and eastern United States, usually supposed to be glacial, are indeed such, and if there is not sufficient reason for assuming the Canadian highlands to have been the source of the glaciers which produced these phenomena, then the source of them must be sought for elsewhere.

I think it will be conceded by all geologists who have studied the glacial phenomena of these regions that both the character of the erratics and the direction of the scratches upon the rocks show that this source must lie to the northeast. Following the line of the glacial movement across Baffin's Bay and Davis' Strait to Greenland, we find that the largest body of land in the northern hemisphere, covered by ice and snow to a depth of not less than 2,000 feet, and at this moment sending down its icebergs as far as the Middle Atlantic. From the sixtieth degree of latitude to above the eightieth, this vast area of land is known to be ice-covered, and from the scarcity of the icebergs upon the eastern compared with the western coast of that land, it may be concluded that the general slope of the surface is to the southwest, and in exact direction of the glacial markings of what is known to have been the course of transported bowlders in Northeastern America. Moreover, if we bear in mind the certainty that during the Glacial period the glaciers moving from the heights of Greenland toward the sea could not have formed detached icebergs as now, but must have for the time blocked up all avenues except the one of easiest escape for the immense accumulations of ice, we may easily assume that this avenue was southwestward across British America and the northeastern part of the United States.

Finally, it may be remarked that this view is strongly confirmed by comparison of the Scandinavian with the American glacial area, for in addition to the identity of the general phenomena there is observable a marked resemblance in the proportion between the extent and other circumstances of the two areas, and that by allowing due weight to all the evidences adduced in support of the view that Greenland was the source of the glacial phenomena of the area in question, we find a probable and rational solution of a hitherto unsettled problem.

Note on the Glacial era; by JAMES D. DANA. — Professor Torell, in his important paper on the Glacial phenomena of North America, supposes that we differ in our views. It is a pleasure to know that we agree in all essential points. No American geologist holds, so far as I know, that "the source of the eastern ice-fields of North America is to be sought in the Canadian highlands." In my papers on this subject in this Journal for 1871 (ii, 324) and 1873 (v, 204), I was speaking of the "Glacier of New England," that is, the New England part of the great glacier; and, the conclusion arrived at was that the glacial scratches over New England, New York, and the region of Canada just north, *converge* toward an area on the Canadian watershed; and hence that the movement over New England and New York diverged from this area. I say that "the scratches of Eastern

Canada, of the high land of Northern New England, of Eastern and Western New York, and of Northwestern Canada, point to a part of the Canada water-shed between the St. Lawrence Valley and Hudson Bay as the head of the glacier that moved southeastwardly over New England." I regret that my words were in any way calculated to mislead. Professor Torell corrects the above view by making Greenland the great source; but to put Greenland in the above sentence would make it absurd, for no height of ice in that land, so far to the northeast, could have determined *southeastward movements over New England.* I did not doubt that the ice mass of the Canada water-shed, continued northward or northeastward, in the direction of the region of greatest precipitation, as the chief ice-mass of the continent; but only whether the increase of height in that direction exceeded enough that on the water-shed to cause movements in the directions indicated. I concluded that the height of the ice-surface on the water-shed would have had to have been at least 13,000 feet to have given it a slope of even fifteen feet a mile to its discharge in the ocean south and east of New England and ten feet a mile to the ice-surface over Mount Washington—the smallest pitch that seemed to be capable of producing the southward and southeastward movement; and the adding of ten feet a mile to the height farther north, thus increasing this already incredible altitude I allude to (ii, 328) but with an improbable *if.* The region of greatest height to the north of the water-shed I did not consider, because it was not within the range of my subject—the source of the "New England Glacier;" and I had no satisfactory facts as to the present amount of precipitation to the north, much less any data for judging of the hygrometric condition in the Glacial era.

In this Journal for April, 1875 (ix, 312), in citing facts from Dr. Bell, in the Report of the Canada Geological Survey for 1873-4, I observe that the facts from the vicinity of Lake Winnipeg show that a line of greatest glacier height was continued from the ice-summit on the Canada water-shed northward; but not necessarily that the height northward "was as great as over the water-shed," for "the greatest height would have been where there was the greatest amount of precipitation, supposing the melting the same." I then explain the absence of the glacier from the central regions of the continent (exclusive of the Rocky Mountains) by reference to the small amount of precipitation (referring to Schott's Rain-chart), and to the high degree of summer heat, thus making the glacier, as I state, a great coastward ice-mass, thinning out to the westward; and the Continental ice, not an ice-cap, but, as I say in a subsequent note (x, 385, 1875), an "ice-mantle thrown about the pole and descending along the borders of the Continent, especially the eastern."

[From the American Journal of Science and Arts, Vol. XV, April, 1878.]

ON THE

DRIFTLESS INTERIOR OF NORTH AMERICA.

By James D. Dana.

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1. *Driftless area of Central and West-Central North America.*

In the number of this Journal for April, 1875,* I have accounted for the absence of the northern drift from the interior of North America—over the great region between Western Iowa and the Sierra Nevada in California and the country north to an undetermined distance—on the ground of the dryness of the climate in connection with the heat of the summer; and I referred for the facts on the former of these points to Mr. Charles A. Schott's very valuable memoir on the "Precipitation in rain and snow in the United States," published in 1872 by the Smithsonian Institution. As the subject is one of great interest I here reproduce portions of two of Mr. Schott's charts (see beyond); one (No 1) giving the lines of equal precipitation for the winter months, December, January and February, and the other (No. 2), the same for the year. The number of inches along the course of each line is marked on the line.*

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* Vol. ix, p. 312. Further, vol. x, p. 385, and vol. xiii, p. 80. The connection between the distribution of the ice and the amount of precipitation is appealed to also in ibid., v, 206, 1873, and illustrated from Mr. Schott's chart.

It will be observed on the chart of the *winter* precipitation (No. 1) that the area of *two* inches or less for the precipitation of the winter months spreads into Western Iowa and part of Minnesota. On Mr. Schott's complete chart, it is shown to cover the whole area (some mountain ridges not being considered) from Central Kansas nearly to the Sierra Nevada; from Iowa and Minnesota to Salt Lake City; and from Minnesota northward and westward. The line of *four* inches, as the copied portion of the chart shows, passes along the eastern border of Kansas, and through Central Iowa and Wisconsin, and thence northward. It runs north of Salt Lake City near the line of *two* inches for 150 miles, and thence—while the latter diverges eastward—continues northward along the summit of the mountains.

In contrast with this, the winter precipitation over New England is 8 to 12 inches; over New York, 6 to 10 inches; over Ohio and Indiana, 8 to 10 inches; over the Southern States, from Virginia to Georgia and Louisiana, 10 to 20 inches.

On the chart No. 2 is given the amount of *annual precipitation* for this same region. While this amount is 40 to 45 inches in New England; 40 to 50 inches from Pennsylvania southwestward; and 40 to 45 over Ohio and Indiana, the line of 20 inches (half the average for New England, Pennsylvania, Ohio, and less than half for the more Southern States) crosses Western Minnesota and passes just west of Iowa; and the line of 16 inches enters Minnesota. Mr. Schott's chart shows that the area over which the precipitation is only 12 inches or less up to 16 inches embraces (exclusive of parts of the Rocky Mountain summit not considered) the wide area from the meridian of 96° in Minnesota and from that of 98° in Southern Dakota, to the meridian of 121° in Oregon, or 23 to 25 degrees in latitude; and from the meridian of 102° in Nebraska and Kansas to Virginia City in Nevada, near the meridian of 117°. North of the United States the lines are not given; but it is well known that the breadth of the area does not diminish in that direction.

At the same time it is to be considered that the *isothermal* lines, and especially those of the summer, bend far northward over the dry region. The climate consequently would have necessarily occasioned over this central and western area of the continent, only a small amount of precipitation in the Glacial era; and all the observed glacial facts prove positively that it

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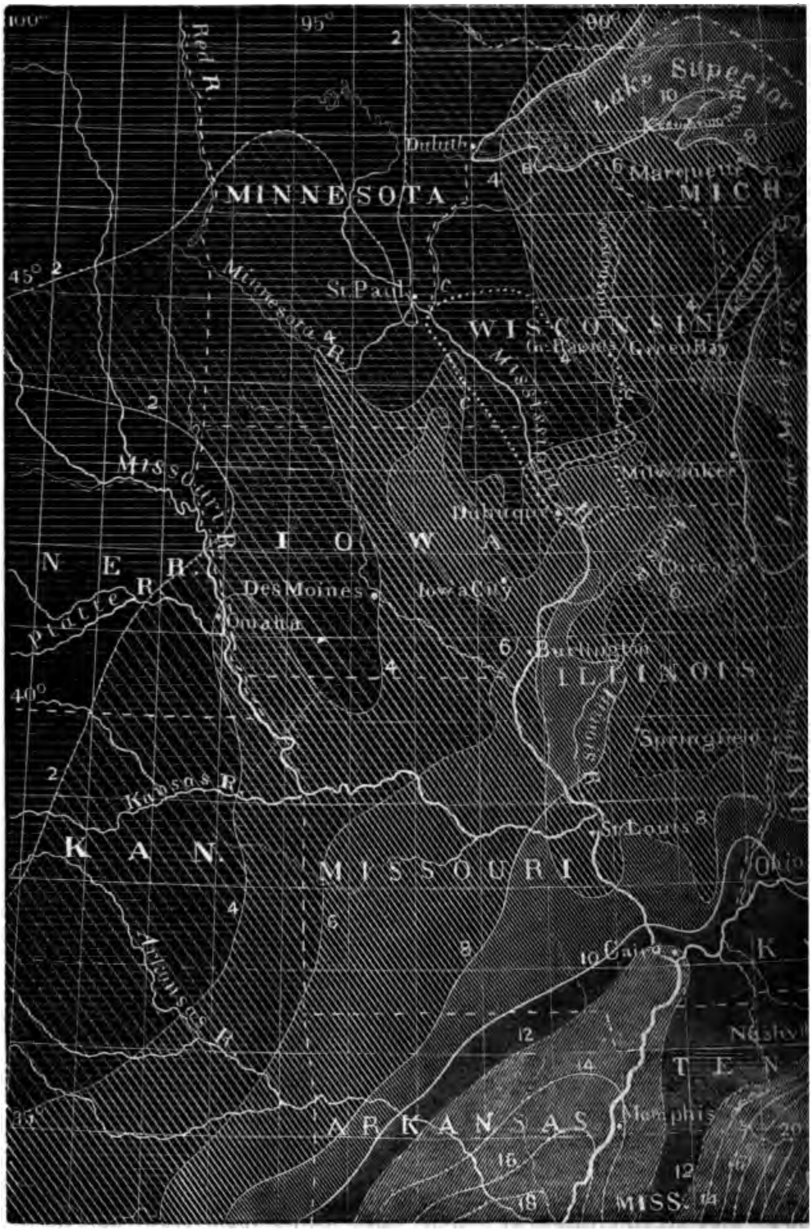
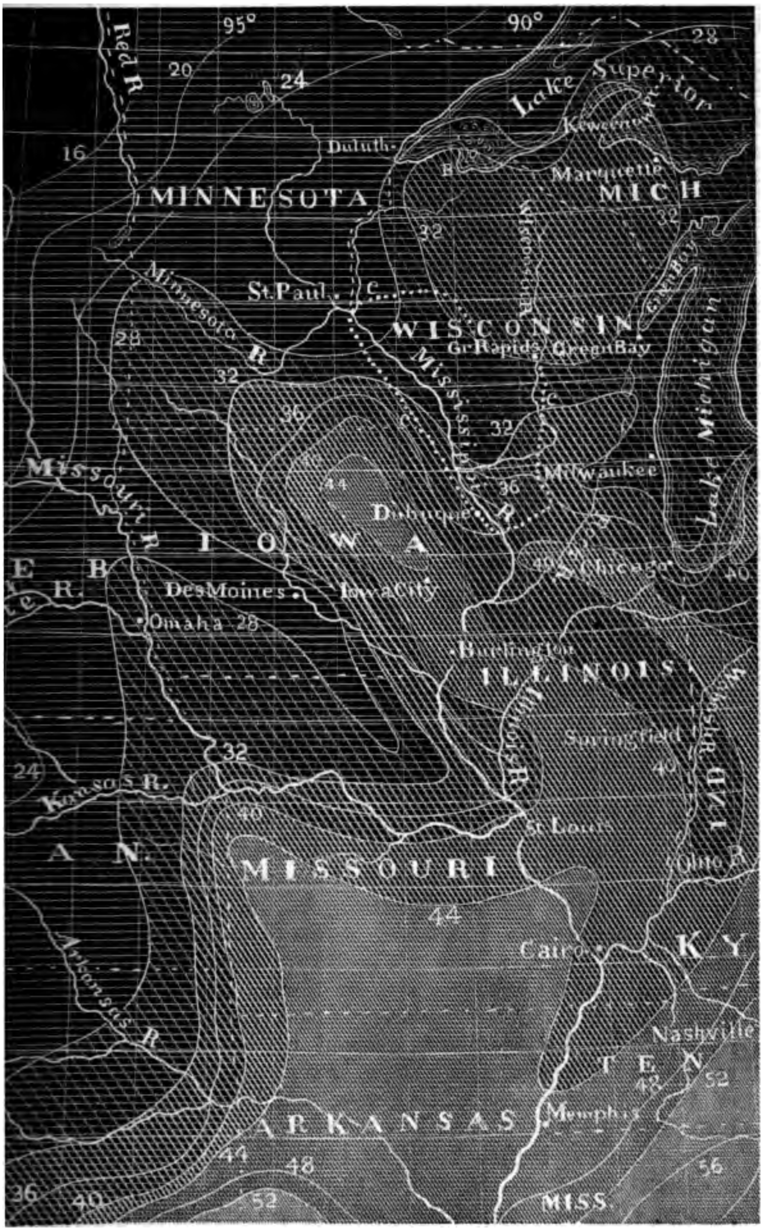
* In the western portions, the line 2 of No. 1, and 16, 20 and 24 of No. 2, are, according to Mr. Schott, only approximations.



1. Lines of Equal Winter Precipitation.



2. Lines of Equal Annual Precipitation.

was too small for the production of a southward moving glacier. The southwestward direction of the scratches and of the bowlder-movement over the area from Wisconsin to Lake Winnipeg not only sustains this, but shows also that the ice had its greatest height over the region of greatest precipitation somewhere between the line from Wisconsin to Lake Winnipeg and beyond, and that of the Atlantic coast. More facts are needed before the northern limit of the glacierless and driftless area can be laid down.

2. *Driftless area in Wisconsin.*

The charts accompanying this paper have been introduced here partly to exhibit the bearing of the climatal facts on the question as to the origin of the "driftless area" in Wisconsin, a description of which is given, from Professor Irving's Report, on page 61 and beyond of this volume. The outline of this driftless area is indicated on the two maps (Nos. 1 and 2) by a dotted line, lettered *c*, *c*, *c*, *c*. It is a striking fact that on the *winter* chart (No. 1) the driftless area is almost wholly included within the area which has only 2 to 4 inches for the amount of winter precipitation; that this area of 2-to-4 inches fall extends in that direction like a deep bay between areas of greater precipitation. To the northeastward of it the amount of precipitation increases from 4 to 10 inches, the last being that on Keweenaw Point, and southward and southwestward over Illinois and part of Iowa to 6 and 8 inches. All of the Wisconsin driftless area, excepting its southern portion, is within the 2-to-4 area. Again, on the chart of *annual* precipitation (No. 2), this driftless area (excepting its south end) is the driest part of Wisconsin, the amount of precipitation over it being below 32 inches, while it is 32 inches or over to the northeast, as far as Keweenaw Point, and to the south and southwest.

It seems therefore probable that the driftless area was located to a large degree by the climate. At the same time Professor Irving's suggestion is needed to make the explanation complete. For this area was not a continuation southeastward of the great central driftless area of the continent, as it is hygrometrically, but, on the contrary it was wholly surrounded by moving ice; for the ice is proved by bowlders to have extended on the *west side* of the area from the southwest end of Lake Superior over Minnesota and Iowa, and even beyond into Missouri where large bowlders occur. The locality of the mass of native copper found in Lucas County, Southern Iowa, is distant four hundred and sixty miles from Keweenaw Point, its probable source. From Iowa the ice stretched eastward across Illinois to the Lake Michigan region.

This southwestward prolongation of the glacier from the western half of Lake Superior over a region as dry as that of the Wisconsin driftless area appears to be a consequence, as Professor Irving urges, of the great depth of the Lake Superior trough—over a thousand feet below the present surface of the water—and its lying in a southwest-by-west (or about S. 55° W.) direction, which was nearly that of the glacier motion in that part of North America. For this would have determined the movement of a great ice-mass southwestward, over the northern half of Wisconsin, and over Minnesota, and thence across Iowa, where there was again abundant precipitation. The annual precipitation is 32 to 40 inches over Eastern Iowa, Illinois, and the region about the southern part of Lake Michigan.

With such a driftless area within the glacier limits—an area without depth of ice enough for movement—the pitch of the upper surface of the ice around it would have been quite various. The height must have been great enough in the eastern part of the Lake Superior region and north of Keweenaw Point to have determined movement through Minnesota and Iowa to Missouri, a distance of five hundred miles, this being shown by the bowlders of copper. Whatever the pitch along that course, it was twice as great toward the Wisconsin driftless area, since the northern border of the area is hardly half as far. Down Lake Michigan the pitch continued into Illinois and Indiana; but the Kettle Range west of Lake Michigan, running along the east front of the driftless area, marks out, as Professors Chamberlain and Irving show, its moraine termination in that direction.

The eastern parallel branch of the Kettle Range lying between the Green Bay Valley and Lake Michigan, which, according to these geologists, is also a moraine ridge, is evidence, as they observe, that at the time when it was formed, the glacier of Green Bay Valley was distinct from that of Lake Michigan. It seems probable that when the Glacial era was at its height, the two were merged in one glacier; but that later, as the ice diminished, the former became independent, and that then the eastern Kettle Range was made.

3. *The earth's axis had the same position in the Glacial era as now*, if the driftless character of the Wisconsin area depended on the climatal conditions explained. The concordance between the limits of the drier areas of the Glacial era and those of the present time, and especially the fact in this respect with regard to the isolated area in Wisconsin sustains this proposition. The probability that such was the truth was long since made apparent by the observation that the southern termination of the glacier in North America and Europe was very nearly along what is now the course of the same identical isothermal. The position and extent of the Wisconsin driftless area afford more precise and positive evidence.

ROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXII, DECEMBER, 1881.]

n *the relation of the so-called "Kames" of the Connecticut River Valley to the Terrace-formation;* by JAMES D. DANA.

SINCE the publication of my papers of 1875 and 1876 on he stratified drift of Southern New England treating espe-ially of the character and effects of the flood closing the era f ice, large additions have been made to our knowledge of the erraces of the Connecticut Valley, and of some other parts of Northern New England, through the New Hampshire Report f Mr. Warren Upham, published in 1878.* In his Report, Mr. Upham describes in detail the stratified drift or terrace-formation of the valley; gives the heights of the terrace above the river (and above mean tide) from careful leveling along its course, commencing near the source of the river i Connecticut Lake, 1618 feet above the sea; discusses th origin of the deposits and of their various features; and pre sents his very valuable topographical details on a map of th valley occupying a series of plates. Besides the ordinar stratified drift, Mr. Upham finds gravel ridges or deposits t which he applies the name "Kames." According to his obse vations, the "kames" were formed before the deposition of th beds of the terrace-formation and after that of the till or u stratified drift, so that they represent an intermediate stage the progress of the era and call for special explanations.

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* Geology of New Hampshire, Part III, Chapter i, Modified Drift in New Hampshire, by Warren Upham, pp. 3–177. 1878. A synopsis of Mr. Upham's Report, by its author, was published in this Journal, vol. xiv, p. 459, 1877.

The facts from the Merrimac Valley also are presented in similar way, and with like deductions.

In the study which I had made of the Quaternary of Sout ern New England, and less perfectly of drift-phenomena els where, I had been led to refer all the stratified drift abo the till to the terrace-formation; and no later obser tions in river valleys had resulted in the discovery of a thing answering to Mr. Upham's "kames." During the p summer, I have been over the region of the Connecticut V ley described by Mr. Upham, in order to obtain a full und standing of his facts, so as to be able to incorporate them wi the knowledge I had previously acquired, and I here give account of what I observed, with my conclusions.

That the subject may be rightly apprehended, I preface m statement with a brief mention, first, of some of the genera facts respecting the stratified drift-deposits which I had gath ered from personal study, and, next, of the facts and deduc tions which are brought out by Mr. Upham with relation t the "kames."

I.—(1.) Scratched bowlders and till are almost uniform absent from the valley terraces of New England and from th stratified beds that make the terrace-deposits. Exception occur where the underlying rocks having till over them com so nearly to the surface of any terrace that the till outcrops.

(2.) The layer of till of the hill-slopes is continued beneat the terrace deposits; showing that along the valleys the till wit the bowlders was generally deposited first.*

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* In the street adjoining my own house, in New Haven, a trench, excavated f a sewer, passed through ten feet of stratified drift, or of the terrace formatio and then opened into a deposit of gravel and scratched stones (including son bowlders of eight to ten cubic feet); and, below two or three feet of this kir of material, entered the Mesozoic sandstone of the region. This sandstone ris in a ridge, above the level of the terrace 400 yards to the north of the excav tion, and must have constituted [illegible] and bottom of the valley-waters the time of the deposition.

(3.) The stratified drift of the valley consists ordinarily of fine material below, and coarser toward or at the top; the bottom portion being commonly of clay or loam, or fine sand with frequently more or less clay; then, following this, layers of sand often fine, but often with more or less gravel; then above, toward the top in the upper fifteen or twenty feet, coarser gravel, and in some regions cobble-stone beds; an order of arrangement, which indicates—in accordance with ordinary hydraulic principles—that the flow of the depositing waters was, as a general thing, less rapid at the time of the early depositions, and most so during the later or that of maximum flood. Exceptions exist along those streams that were torrents, and sometimes at the mouths of tributaries to large streams.

An uppermost sandy layer, of two or three feet thickness, frequently exists, indicating that the ebb commenced in a lessened rate of flow.

(4.) The portion of the terrace formation in a river valley that is nearest to the river or adjoins the channel-way, may, and often does, consist largely of beds of coarse gravel or cobble-stones, while one or two hundred yards away from the river it is composed chiefly or wholly of beds of sand; the river-border deposits being thus coarse because of the sifting or assorting action of the stream in violent flow along its channel or against one or the other side of it. And the coarseness may diminish down stream, because of greater remoteness from the source of coarse material, and also because of a change in the rate of flow, producing less power of transportation and so allowing of a deposition of the sands drifted out above.

(5.) Terraces of different degrees of coarseness and of different heights were sometimes simultaneously made on opposite sides of a stream, owing to the different rates of flow in the waters along the two sides.*

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* Along the middle one of three streams entering the New Haven Bay, called Mill River, coarse gravel and cobble-stone deposits characterize the New Haven terrace-formation all the way to the harbor; they are vastly coarser on the west side of the stream than on the eastern, and in the southern part of its course are most so along a more western line away from the present stream. Moreover, the deposits make a terrace on the *west* side of the stream of only twenty-five feet above mean-tide level, while on the *east* side, where the material is so much less coarse, they rise to a height of forty-three to forty-five feet, or the ordinary level for the New Haven plain at that distance from the Sound. Those coarsest beds were made under the sifting action of the violently flowing waters (the pitch of the stream for some miles back being eight to ten feet a mile), and hence, that is, because of the loss of the finer material in this way, the height attained on the side of most rapid flow was twenty feet below the normal height. Moreover, the violent waters were probably those of the nearing maximum stage of the flood; for the coarse [illegible]l deposits (as various sections show) extend down but fifteen feet from the [illegible], and rest on beds of sand and fine gravel.

(6.) The terrace-formation of a large and broad valley was made mainly, not from what its river transported, but from the contributions of tributaries. Consequently, (*a*) the height of the maximum flood is best registered in terraces at the mouths of tributaries, and (*b*) where tributaries fail for long distances, there may be only low terraces; further, (*c*) the coarsest gravel beds should exist in the deposits about the mouths of tributaries, and especially in those made along the banks of the *main river* near these mouths, where the contributions were subjected to the sifting action of the swiftly flowing river.

(7.) The extent and height of the terraces made along any part of a valley depended not merely on the amount of contributed material, but also largely on the size and form of the valley. Where very wide and deep, like many lake basins, the deposits were generally sufficient to make only low or narrow terraces; where narrow, the flow of waters was sometimes, because of the diminished width, too rapid for any depositions; but where the valley, though narrow along the main channel had a broad region of ledges on either side that became overflowed when the waters were nearing their maximum depth, a high terrace might then have become of great width; for the shallow region favored deposition by offering resistance to the flow, and however wide needed little material to cover it. Just as this condition favored the making of a broad upper terrace, so it favored the making of a wide terrace at lower levels, especially if the flow of water continued long at those levels.

(8.) Ice-floes, bearing sand, gravel and bowlders, added to the transported material for the terrace-formation; and they should have been abundant during the breaking up, at the time of maximum flood. Being carried by the waters, their distribution of material would have taken place for the most part in accordance with the principles above explained.

II. Mr. Upham adopts in his New Hampshire Report, the view that the valley formations are deposits made by the flood from the melting glacier, and it appears from his explanations that he would accept without objection several of the above explanations. The points of discrepancy, however, are many and important. I cite here only those relating to the "*kames*," and mostly in the author's words. The term *modified* drift is used by him for *stratified* drift.*

Page 12. "The oldest of the deposits of modified drift are long ridges, or intermixed short ridges and mounds, composed of very coarse water-worn gravel or of alternate layers of gravel and sand irregularly bedded." "Their position is generally along the *middle* or *lowest parts* of the valleys." Wherever the ordinary fine alluvium of any terrace occurs adjoining a kame, "it overlies or in part covers the kame deposits," the ordinary terraces being of later formation than the kames

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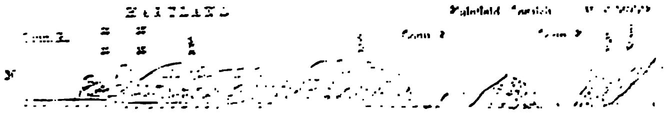
* I have avoided the term *modified*, because it is not known to express in all cases the truth, preferring the non-committal term *stratified*.

Page 43. Along the Connecticut, between Vermont and New Hampshire "from Lyme to Windsor, a continuous gravel ridge or kame extends 24 miles, along the middle and lowest portion of this valley, with its top 100 to 250 feet above the river." "Its material is gravel and sand in irregular obliquely bedded layers, always showing an inclined, and in most cases a distinctly anticlinal or arched stratification. The gravel, which always forms the principal part of the ridge, varies in coarseness from layers with pebbles only 1 or 2 inches in diameter to portions where the largest measure 1½ or 2 feet. The fine kinds prevail." "The sand is usually coarse and sharp, well suited for masons' use: it occurs in layers of varying thickness up to one or two feet, but sometimes it is wholly wanting." "All the materials of this kame. and of its remnants along this valley, are plainly water-worn and stratified."

Page 44. "The most important feature of this kame, if we compare it with others in New Hampshire, is that along its entire extent it constitutes a single continuous ridge which runs by a very direct course nearly in the middle of the valley, having no outlying spurs, branches, parallel ridges or scattered hillocks of the same material associated with it."



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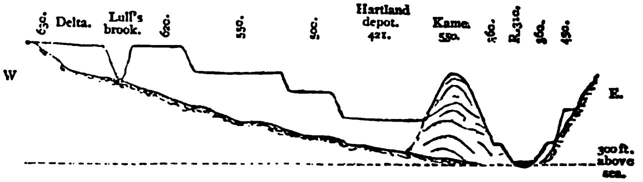
The preceding figure is part of a section, given on p. 45 of the Report, intended to show the general features of the southern part of this kame ridge (exaggerated relatively in height) in Hartland and Windsor; and the following (from p. 40) is a transverse section of the Connecticut valley through the Hartland deposits, exhibiting the position of the kame just west of the river channel, and its relation to the terrace-formation and the several terraces of the valley.

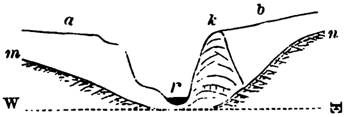
2.



Transverse Section in Hartland and Plainfield.

The adjoining figure, from page 37 of Upham's Report, will help further to explain the author's views. It represents the Hanover "kame," with the outline of the terrace-plains on the opposite sides of the Connecticut. The kame, *k*, is represented as constituting a ridge, coarsely stratified, buried beneath the terrace formation, up to its very top, on the landward side, but uncovered on the side toward the river. A section taken a little farther north would have exhibited the "kame" projecting above the terrace-plain.

3.



Section of the Hanover Kame, *k*, on the east side of the Connecticut River, *r*: *m n*, the till-covered underlying rocks; *a*, terrace in Norwich 505 feet high above mean-tide level and 132 feet above low water in the river; *b*, terrace in Hanover 515 to 545 feet high.

" Kames" are also described as occurring in the valley to the north, but at long intervals.

As to origin:

P. 176. The kames " were deposited, as explained on pages 13 and 14, by glacial rivers, at the final melting of the ice sheet, in *channels formed upon the surface of the ice.* When the bordering ice-walls and its separating ridges and masses disappeared, the gravel and sand remained in long steep ridges, or in irregular short ridges and mounds."

P. 44. The infrequency of angular fragments and bowlders shows "that the kame of the valley was formed in an open ice-channel." P. 14. On the ice in these "channels were deposited materials gathered by the streams from the melting glacier. By the low water of winter, layers of sand would be formed, and by the strong currents of summer, layers of gravel, often very coarse, which would be very irregularly bedded." "The glacial rivers which we have described appear to have flowed in channels upon the surface of the ice, and the formation of the kames took place at or near their mouths, extending along the valley as fast as the ice-front retreated." P. 44. "When the river entered upon the work of excavating its present channel in the alluvium, the kame was a barrier which confined erosion to the area on one of its sides and protected its opposite side; so that this ridge of gravel often forms the escarpment of a high plain with the river flowing at its base."

The chief points urged by Mr. Upham with regard to the so-called "kames," exclusive of those pertaining to mode of origin, are:—origination: after the till and before the stratified drift of the terraces; material: chiefly beds of gravel; structure: usually arched or anticlinal; situation: generally between the river and the upper terrace, and often making the riverward limit of the latter, also, in many cases, partially isolated and ridge-like, owing to a depression between it and the terrace, and sometimes a large depression; height: frequently the same with that of the upper terrace or a little above it. Further, his descriptions show that he refers coarse cobble-stone deposits in the riverward part of the terraces always to "kames."

In my study of the facts relating to the Connecticut Valley "kames," I commenced at Windsor, the southern limit of the great line of "kames," and examined the valley formations at various places from that place to Lyme, and thence northward to Barnet and Lancaster: and the report I have to make is unfavorable to the "kames." I made levelings at various places in order more surely to identify the terraces mapped by Mr. Upham, and to apprehend their true relation to the Connecticut Valley, and also, to add, if possible to the facts. My trials soon satisfied me as to the essential correctness of his measurements.

Windsor.—At Windsor (on the west side of the Connecticut) the upper terrace of the village rises to a height of about 216 feet above the river or 520 feet above the sea-level. I saw no good opportunity for a satisfactory examination of the material of its lower part beneath the village; but in the upper part found it to be fine sand and loam, though somewhat pebbly through the upper 25 feet.

South of the village lies Ascutney Pond, a north and south body of water made by damming the waters of Ascutney brook; on the *east*, the pond is separated from the Connecticut River by a ridge of stratified material, nearly flat-topped, having about the same height as the upper terrace. Mr. Upham says, somewhat doubtingly, that this ridge "seems to be a kame deposit." It ends southward in rocky ledges. A mile and a half farther south, the high river terrace consists along its eastern margin of very coarse gravel, and is pronounced therefore to be in this part the "remains of the kame."

I found this ridge east of Ascutney Pond to consist mainly of loamy material, or sandy loam, like the terrace west of Windsor, with little gravel and that chiefly over its upper surface or in an upper layer. But directly *west* of the Pond there is a terrace (not referred to particularly by Mr. Upham) whose material is made up largely of coarse gravel, in part cobble stones, and coarsest in its upper layers, which in this portion is as much entitled to be called "kame" as that "a mile and a half farther south." This terrace rises westward to a level plain at 448 feet above the sea-level, and then another at 480, and this last rises to 525 feet, which is the height given by Upham for the possible "kame" east of the pond. Its gravelly character continues, but diminishes northward.

I found no evidence whatever that the eastern portion of the terrace was a "kame," that is, a part separate in time of origin from the rest; the evidence was all against such a conclusion. Moreover there was an abundant source at hand for the amount of coarse gravel and cobble stones; for Ascutney or Mill Brook, rising in northwest Reading, flows with rapid descent by the north side of the lofty Ascutney Mountain (3320 feet), and would have been a great transporter from the drift-covered country it drained. The position of the stream, and its relation to the southward-flowing Connecticut, account for the distribution of the "kame" material or coarse gravel of the Windsor region, including that of Windsor village, mentioned by Mr. Upham, and also for the isolation of the ridge on the east side of the pond.

Two miles north of Windsor a kame is entered on Mr. Upham's map. Much coarse gravel here makes the outer or westward portion of the upper terrace, which is by the map 500 feet above the sea-level. Besides coarseness of gravel, I saw no evidence of a kame, that is of any deposits that were distinct from the terrace in original deposition. A brook comes from the west just north of the "kame."

Hartland station, 4½m. north of Windsor.—At this place stands the "kame" ridge represented in Upham's section reproduced, on page 456, of which he says: "At one place, east of Hartland depot, this plain (that of the upper terrace) has been swept away from both sides, and the kame forms a conspicuous steep ridge 125 feet in height [above the depot plain, 240 feet above the river]. Wherever it is exposed, it is readily recognized by the pebbles which strew its surface, and which are very rarely found in the ordinary modified drift of the valley."

I ascended this prominent "kame" with my interest greatly augmented by the description in the Report. The narrow plain between it and the station (see the section) was covered with pebbles from an underlying gravelly layer. The same gravelly layer made apparently the base of the "kame," for some loose cobble-stones were found at the base of the slopes and for 10 to 15 feet above. But on ascending the ridge, no gravel was anywhere observed at a higher level; on the contrary, all was fine loam or fine sandy loam to the very top. And on descending, the same proved to be true; the only gravel was at its base, 50 feet above the river and nearly 200 feet from the top, according to my leveling. There were no good sections, but if made of gravelly layers, loose stones or pebbles would have worked out to the surface and shown themselves somewhere over the earthy sides.

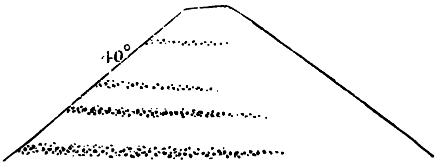
A few rods west and northwest of the Hartland depot there was gravel in the terrace, and much of it; and according to the description of "kames," there was, as far as material goes, a "kame." On the first terrace-plain, about 65 feet (by my leveling) above the railroad track (or 486 to 490 above the sea level) large stones (1 to 10 inches across) lay over the surface, and very many in the sloping section of it facing the railroad track. From this terrace-plain, some rods to the west, there is an abrupt rise to the next higher terrace, and here the material is fine sandy loam with no pebbles. The natural conclusion is that the gravelly stratum is a lower part and the sandy loam an upper part of the same terrace formation, precisely as in the so-called "kame;" and, secondly and accordingly, that the "kame" is nothing but a piece of the terrace-formation. Lull's Brook here comes in from the west and is no doubt accountable for the coarse gravel.

North Hartland, nearly 4 miles north of Hartland.—At North Hartland station, there commences, according to Upham's map, another "kame" a mile long; it is near the river, close by the west side of the railroad. Its height by the map is that of the upper terrace-plain, or 550 to 560 feet above mean-tide level. Very coarse gravel shows itself in an oblique section of the terrace formation or "kame" facing the railroad, becoming cobble-stone layers 70 to 80 feet above the track. The coarseness diminishes to the northward. The large torrential stream, Quechee river, rising in the Green Mountains, enters the Connecticut here, and seemed to be a sufficient source for all the depositions; while the fact that the contributions were contributions to the Connecticut, which was in rapid flow off its mouth, accounted for the distribution of the especially coarse accumulations along the riverward border of the terrace.

In Hartford, Vt., at White River Junction, 4½ miles north of North Hartland.—On the west border of the Connecticut about White River junction, or at the mouth of White River, there is a short "kame" according to Upham's map south of this river, and one, a mile and a half long, north of it. The White River valley is here very broad, like a piece of the Connecticut, and as it rises westward but slowly, it opens to view a portion of the Green Mountain range, which is the chief source of its waters. The Connecticut valley terraces of the region are high—not far from 180 to 235 feet above the river, or 510 to 570 above mean tide level; but that to the north, owing to the retreat in the hills is much the most extensive, and hence the greater length of the northern of the two "kames."

The *southern "kame"* commences within a few yards of the railroad station and hotel, where an excellent section of it is exposed to view. The pitch of the slope toward the Connecticut is about 40°. The structure is well-bedded throughout. The layers consist of cobble-stones, finer gravel and coarse sand. The coarsest cobble-stone layers are below, and some of the rounded stones from them are one to over one and a half feet in diameter. Other cobble-stone layers, less coarse, occur at different levels above, alternating with an increasing thickness of gravel; and toward the top, which is near the top of a terrace-plain, the material is finer gravel and sand. Fig. 4 shows the position of the cobble-stone beds in the upper half of the section. The beds are not continued through the figure because in the western portion of the section the layers were mostly concealed by slides; but it was manifest from the few and smaller stones on the surface that there was a marked diminution in coarseness to the westward even in the first 100 yards.

4.



Upper part of the section of the "kame."

The cobble-stone beds exposed to view in the section stop short off below at a level about 20 feet above the level of the railroad track, or 56 feet above the river (low water), and underneath occurs a bed of coarse sand, having the flow-and-plunge structure well marked. A section of the same sand-bed was observed 70 yards to the south, evincing that it is not a local deposit. But the depth to which it was exposed was hardly 8 feet; and it may be that there are other stony layers underneath. Above the top of this section there is a nearly even terrace-plain, 160–170 feet above the river, or 493 to 503 above mean-tide level. This plain rises to the southwest to a maximum height (not observed by Upham) of 570 feet. The material is fine sand and sandy loam. But along the riverward border of this terrace plain, where it is lowest (493 feet), stands a steep narrow ridge, 50 to 65 feet high, which, judging from the stones of its surface, is made chiefly of beds of cobble-stone gravel. The top is 546 feet (Upham), above the sea.

The cobble-stone character of this ridge and its position make it eminently "kame"-like. But the evidence from the section described, as well as from the plain around, is directly opposed to the idea that it is the top of a buried gravel ridge, existing there before the terrace material was deposited.

In the section, the obvious facts are: that these upper cobble-stone beds—those of the top ridge—are underlaid, first by layers of sand and fine gravel, and then below by alternations of coarser beds; that all the beds are horizontal instead of arched; that they diminish rapidly in coarseness westward, or up White River, showing this even in the first 100 yards, and less rapidly southward or down the Connecticut, the coarsest deposits being at the angle in the terrace formation between the two streams. All the beds are evidently those of the terrace-formation, and the cobble-stone ridge at top is the youngest instead of the oldest.

The *northern "kame,"* or that north of White River, commences about half a mile from the railroad station. A section is exposed to view at its southwest angle, facing White River, exhibiting very similar features to those presented by the northern kame near the railroad. It is horizontally bedded throughout, and the coarsest beds are below; and some of the rounded stones from the beds are two feet in diameter.

But the cobble-stone beds are of less extent, for they reach only to a height of 45 feet above the railroad track, or 81 above the river, and are coarsest at 16 to 26 feet. Above the 45 feet the beds are of coarse and fine gravel, and increasingly finer to the top of the terrace, 510 feet (Upham) above mean tide. Below 15 feet above the railroad the beds are concealed.

On the top of the high terrace, along its riverward border, some spots of cobble-stone gravel occur, but no distinct gravel ridge like that of the southern kame.

The interior of this "kame" is fortunately more or less perfectly exposed to view in both *longitudinal* and *transverse sections*; and it is remarkable that these sections have nothing "kame"-like in them.

The longitudinal or *north and south* section extends along a cut or gorge commencing close by the west side of the cobblestone exposure just described. The gorge (with its carriage road at bottom), seemingly divides off a veritable "kame" from the terrace west of it; but the beds on the opposite sides of this cut so correspond, that there can be no doubt of stratigraphic unity.

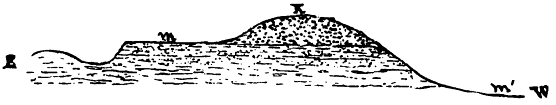
The section of the "kame" along this gorge is more or less obscured by slides, but not in all parts. It shows, first, that the stony beds diminish rapidly in coarseness away from White river or to the north. One hundred feet up the gorge, the cobble-stones are half smaller and extend up to a height of only 30 feet above the level of the railroad, or 66 feet above the river, and beyond this they continue to diminish. At 400 feet up the gorge, the ascending road along its bottom reaches a height of 28 feet above the railroad level, and here, in the exposed section on the *east side*, there is a bottom layer of sand, and above the sand 30 feet in thickness of clay; and this clay outcrops on the west side of the gorge as well as the "kame"-side, proving that the deposits of the supposed "kame" are one in bedding and material with those of the terrace formation, just as the high terrace plain above the whole (510–520 feet) is one from the Connecticut westward.

To the eastward of this section, toward the railroad, the deposits diminish in coarseness; and the same change continues northward along the railroad, where the surface material of the lower part of the terrace-slope shows stones only to a height of 20 or 30 feet, or less, above the track.

One of the *east-and-west* sections of the "kame" exists about half a mile north of the south end. A gorge intersects the deposit which is cut down to the level of the railroad track and extends inward (westward) to the center of the "kame" line. But there is nothing kame-like within it, and least of all at its inner extremity. On its *north* side, it has no cobble-stone beds, not even gravel beds; the material is fine sand delicately straticulate. On its south side, in the part nearest to the river, there occurs, in a large mass that has slipped down from above, a thin bed of small stones (three inches in diameter) with some gravelly and sandy layers below; elsewhere the material is sand. In the inner part of the cut, besides the fine sand, there is a bed of light-colored clay and sandy clay between 60 and 90 feet above the railroad, and above this within a few feet of the top, sand and fine gravel.

There is however one "kame"-like feature. Upon the top of the terrace (here about 510 feet above mean tide), near the inner end of the gorge there is an isolated knoll about 30 feet high, and of rounded form, which has many cobble stones over its surface, some of them 10 inches in diameter—indicative of cobble-stone beds within. It has no continuation north or south. The material of the plain around is sand or fine gravel, like that of the upper part of the section. The following figure shows the position of the gravel-made knoll, the form of the surface north and south, and a section of the beds which according to the facts in the gorge, underlie it. The material of the knoll at top is manifestly the *latest* of the terrace-deposits.

5.



The beds below the level of the railroad were not exposed to view at this place.

The second *east-and-west section* occurs about a fourth of a mile farther north. A long and deep gorge here cuts through the deposits of the 520-foot terrace, nearly to the level of the river, intersecting the "kame" line and extending nearly half a mile to the westward. There is less of kame-like features here than in the preceding gorge. Along the bottom of the deep cut, where a stream flows in some seasons, lay pebbles and some cobble-stones, derived from layers below the level of the railroad track, and these continued for about 300 yards west of the railroad. At a higher level the material is sand or very fine gravel, and the latter in some parts at the top. The sides of the cut were mostly covered by the fallen sands, so that the existence or absence of beds of clay could not be ascertained. A unity of structure from east to west was manifest. Nothing answered to the description of a kame; all was apparently of the terrace formation.

Hanover, New Hampshire, four miles north of White River Junction.—In the town of Hanover, a "kame," according to Upham's map, borders the Connecticut for three miles, to a point north where the river makes an abrupt bend, and thence it follows in the same direct line, the *western* or Vermont side of the river in the towns of Norwich and Thetford, nearly to Thetford village, making in all a length of about seven miles.

The only section of the Hanover "kame" which I have personally examined, is that on the road side between the bridge and the village—the one figured by Upham on page 39 of his Report. At this place, the riverward portion of the stratified drift, or that spoken of by Upham as the "kame," is separated from the following portion by a depression produced by undermining and a dropping of great masses to a lower level, and consequently there are at this place two bluffs, the western which is that of the so-called "kame," and an eastern, which is referred by Upham to the ordinary terrace-formation. In his figure of the section of the kame here exposed to view, it is made to consist of somewhat arched beds, with alternations of coarse stony layers and finer material alike from top to bottom. I found the bedding horizontal, like that of the eastern of the bluffs; its beds, composed largely of sand and fine gravel, with but few of cobble-stones: and the top portion made of very fine sand, identical in its light color, fine straticulation and other features, with the top portion of the eastern bluff. The latter bluff differs in consisting throughout of stratified sand, and this difference between the deposits near the river and those more remote is not uncommon.

Prof. O. P. Hubbard, of the Medical School of Dartmouth College at Hanover, and formerly Professor of Chemistry and Geology in the Academic Department, has obtained for me the following additional facts respecting the region of the supposed "kame."

He states that no coarse gravel or cobble-stone beds exist along the top of the "kame" *south* of the above mentioned section for the half mile to Mink Brook, and none *north* of the same for nearly a mile, so that this kind of evidence as to the existence of a "kame," fails in these portions. Farther north, above the village of Hanover, there is on the "kame" ridge an area of cobble-stones, and two to three hundred yards beyond a this, across a deep cut leading to the river, a grass-covered knoll made up of coarse gravel and cobble-stones, some of the stones a foot or more in diameter. The knoll was found by measurement to be fifteen feet high above the terrace-plain; it marks the spot which is made by Upham, the highest part of the kame, 556 feet above mean-tide level. Prof. Hubbard ascertained with a spade that the knoll was composed of coarse gravel, and *rested on* fine sand or sandy loam like that which makes the top portion of the terrace-formation between there and the village and also at the bluffs described above and elsewhere. He concluded, therefore, that the coarse cobble-stone deposit was but 15 feet thick; and, from the level of the other cobble-stone area, that the latter corresponded in position to the lower portion of this deposit. In the deep cut between the two cobble-stone areas the beds are not exposed, but no stones show themselves, and the material was evidently of the same fine sandy nature. Just south of the more southern area three large excavations have been made on the east side of the "kame" ridge to its top, for filling a bog, and these show only sand; but the northern is so near the cobble-stone layer that some of the stones have fallen into it. The evidence obtained by Prof. Hubbard thus appears to prove that the coarse gravel of the two areas is only the top deposit of the terrace-formation, such as characterizes in many other places its riverward portion.

Norwich, Vermont.—The continuation of the Hanover "kame" northward along the west border of the Connecticut in Norwich, passes, near the end of its second mile, the valley of Pompanoosuc River. About a mile south of this turbulent stream, a road ascends from the borders of the Connecticut River to the summit of the high terrace, crossing the "kame" where its height is 565 feet (Upham), half a mile south of the highest point, 600 feet. Along the road are sections of the deposits, showing the inner nature of the Norwich "kame." Where the road commences the ascent some cobble-stones lie scattered over the surface, such as had been found common along the road at the base of the "kame" for the half mile or more to the south. Above this, for the next hundred feet, there is sand, finely straticulate, with occasional fine gravel. Nearing the top, the beds become coarse gravelly, and then there are large cobble stones; and this upper coarse-gravel portion rises above the general level of the plain, making a low ridge which is the crest of the so-called "kame." In the higher part, to the north, some stones, as stated by Upham, are 4 to 5 feet in diameter and angular.

Nothing was observed on the ascent from the river, or on the west side, to suggest a suspicion that this cobble-stone deposit was the top of a narrow range of coarse gravel beds buried beneath the terrace-formation; on the contrary, the evidence from the sections along the ascent, and especially the succession of beds toward the top from sand beds to gravel beds, and then to the coarse cobble-stone gravel, strongly confirmed the natural inference that all was one consecutive series, with the cobble-stone deposit the uppermost and therefore the latest. West of the cobble-stone ridge, or the "kame," the terrace has great extent. The surface falls off immediately 40 feet, exposing the materials that lie beneath, and these are sand and fine gravel as on the east side.

The Pompanoosuc river was probably the chief source of this coarse material of the summit. To the southwest, about the village of Norwich, the terrace is quite stony over much of its surface from the contributions to the terrace of Blood Brook.

In Thetford the "kame" becomes very low before the village is reached.

The other reputed "kames" of the Connecticut River valley I have not particularly examined, But as the line from Windsor to Thetford is "the kame of the Connecticut valley," essentially "a continuous gravel ridge or kame, extending 24 miles," and is made, in Mr. Upham's work, the text for the description of "kames" in general, details from the other minor "kames" in the valley [illegible] not necessary for a right conclusion.

Conclusion.—The conclusion from the investigation is, as already indicated, the following: that the supposed "kames" are portions of the terrace-formation, with which they usually correspond approximately in height; and that their materials were the same in source with the rest of the stratified drift, and the beds the same in time of origin.

The gravelly character of the terrace-formation off the mouths of the tributaries of the Connecticut is often mentioned by Mr. Upham; and, if the above conclusion is right, the coarse material of the "kames" is to be explained on the same principle. The position of these coarsest deposits, near the borders of the flooded Connecticut, whether they make the lower or the upper beds, is a consequence of the rapid flow of the waters in this great stream, which drifted away much of the finer material within reach and left stones. The coarsest stone beds at the mouth of White River are located where the two streams—both great streams then—join, that is, where the great contributor of gravel and stones encountered the great distributor.

The deposit of gravel and stones in the upper portion of a terrace I have attributed to the violence of the flood when at its maximum stage. But in the region of the so-called "kames," from Windsor to Thetford and beyond, floating ice was probably needed for much of the transportation; and ice-floes would have been abundant at the time, when the glacier-ice was in rapid process of dissolution about the slopes of the Green Mountains—the range at the head of the principal tributaries in this part of the Connecticut valley. At the same time, the Connecticut, by its rapid flow along its eastern side at one time and its western at another, would have determined an accumulation of stony material along its borders, as a great river now produces accumulations on its banks different from those more distant. Here the floating ice with its burden of earth and stones would have been stranded as well as other transported materials. Moreover such deposits might have been raised ten feet or more above the plain adjoining, as now happens on large streams from modern floods. But there is no occasion to account for a cobble-stone deposit along the whole top of any of the so-called "kames;" for, only a small fraction of each has a crest of this kind; or any difference in structure from the ordinary terrace-formation, except that in some cases, near tributaries, they have more of coarse gravel below.

In Haverhill the angular stones and gravel, brought down the Ammonoosuc on ice-floes, made in one place a thick till-like deposit lying unconformably over the stratified drift and continued some distance down the riverward slope of the terrace. This is an exceptional case, due probably to the fact that the White Mountains, the source of the stream, are near by.

But the ridge-like feature of many of these coarse upper de- its, on the riverward part of the terrace-formation, that is, ir standing up 15 to 60 feet above the level of the terrace und, and sometimes higher, is in part, if not chiefly, due to sion. The Norwich stony deposit, on the top, south of the npanoosuc, has a large and broad depression west of it; and as that south of White River Junction, that of Hanover, and ers. Even the little knoll described on page 463 has its ad- ing depressions, as shown in the figure there given, and the h descending from the southern one of these depressions be a further consequence. The waters of rains, making or streamlets, easily remove the sand and fine gravel of the ace-formation; but they make comparatively little impression he beds of coarse gravel and cobble-stones, because of the of the stones and often also their partial consolidation by oxide (limonite). Hence the waters which fall over the y surface find a place of descent and wear away on either ; and with every new inch of descent gained there is a gain all and force, and a quickening of the work of erosion. channel begun is deepened and widened, waters from the n flowing in and helping in the removal: and thus broad nels like river-channels may form over wide plains, and gorges be cut through to their depths if a place of dis- ge is at hand. Besides, the river at the time of greatest ht swept over the terrace plains with often 40 to 60 feet or e of depth, and large denudation in some parts would have the consequence.

he above explanations have reference to those so-called mes" examined by me in the Connecticut River valley. I e no sweeping application of them to those which have been ribed from other regions that I have not seen. It was my ose to have studied, the past season, also the terraces of Merrimack valley, but time failed me.

he gravel ridges of the vicinity of Andover, Massachusetts, described by Prof. E. Hitchcock, and lately studied with and designated "kames" by Prof. G. F. Wright, appear to esent a phenomenon of a different class. I had the guid- of Prof. Wright in a day's excursion over them, and was to think, as he does, that these isolated ridges of unstrati- coarse gravel and stones are of morainic sub-glacier origin; perhaps, lateral, though sub-glacier, moraines, left between es of ice that moved southeastward along the depressions—marsh-filled—which exist either side of them. But without e study of them, and especially of their relation to the de- its of the Merrimac valley, I would not express a decided nion on the question.

Nothing has here been said with regard to the "kettle-holes," that is, isolated kettle-shaped and often pond-containing depressions, which, in Mr. Upham's view, were connected in origin with the "kames;" and for the reason that they occur also over ordinary terrace-plains. Further, Mr. Upham's hypothesis as to the origin of "kames" there is obviously no occasion here to discuss.

Some points in the explanations above advanced need, in view of the difference of opinions among writers, further consideration, and will be made the subject of another communication.

[From the Amer. Jour. of Sci., Vol. XXIII, February, March, May, 1882.]

THE FLOOD OF THE CONNECTICUT RIVER VALLEY FROM THE MELTING OF THE QUATERNARY GLACIER.

By James D. Dana.

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THE FLOOD OF THE CONNECTICUT RIVER VALLEY FROM THE MELTING OF THE QUATERNARY GLACIER.

BY JAMES D. DANA.

THE explanations offered in my last paper * with reference to the origin of the so-called "kames" in the Connecticut Valley, and of terrace-formations in general, suppose certain conditions and results that are fundamentally at variance with other views of Mr. Upham. It is necessary, therefore, to consider the facts bearing on these points of difference in order to clear the subject, if possible, of the doubts with which in some minds it is at present beset. These points involve the question as to the relations between the position, features and heights of the valley-deposits and the depth, pitch and velocity of the flooded river. The latter subjects are consequently among those that are discussed in the following pages. As the Connecticut was one of many flooded streams in Glacial America, the conclusions here deduced, if well established, have an importance as universal as the floods. This difference is however to be noted between New England rivers and many to the west or south of west, that the former were wholly within the glacier-covered region.

In the following pages I, first, briefly state what appears to have been the general condition of the Connecticut and its tributaries during the progress of the flood; and then consider: (2) the origin of the channel-way of the river; (3) the question as to which is the *normal upper* terrace in any part of the valley, or that which most correctly registers the highest flood level; and next, take up the subject (4) of the dimensions, velocity and discharge of the flooded river, and (5) the bearing of the facts on the retreat of the glacier.

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* This Journal, xxii, 451, 1881.

1. *General conditions of the flooded rivers and tributaries during the melting of the glacier.*

1. *Like other river-floods.*—The view to which I have been led by the study of the phenomena of the Champlain period, or those of the melting glacier, is that a *river-flood then* was in most points like a river-flood now. The valleys were, at the outset, deep valleys, and generally of greater depth than at present; for many have thick deposits over the bottom that were left there by the flood.

The waters of the Connecticut, as well as of other streams, rose gradually; passed the ordinary modern limit of 20 to 30 feet; still kept on rising for a prolonged period, owing to the long continuation of the melting and the abundant rains of that eminently *pluvial* era; and, at last, they reached a height of 200 to 260 feet above modern low water in the river. During its progress and continuance, water, bearing sand and often gravel and stones, flowed down the slopes leading into the valley along all the smaller depressions of the surface as well as by the many tributary valleys. Abrasion, transportation and deposition, the ordinary agencies in river action, went forward, as usual, together; and so the waters kept a great channel open along the course of greatest velocity, like a modern river, and transported and deposited according to the supply and rate of movement.

Whenever, finally, the diminution in the supply of water from the melting glacier failed of compensation by an increase in the rains, the decline of the flood began; and, as the river retreated toward its present contracted condition, it dug down into the bottom deposits to make its new or modern water-channel and flood-grounds.

2. *Changes in tributaries with the progress of the flood.*—The waters rose concurrently in the main river and in its tributaries; all had augmented activity together. At first, little streams and large ones may have been alike great transporters of sand and gravel. But with increasing height of flood there would have been changes. Some of the fierce little torrents would soon have become quiet through submergence by the great river. Other longer ones, flowing in rapids from the remoter hills, would have had their embouchures set back, but notwithstanding would have continued their transportation of coarse gravel and finer material to the end, making most abundant and coarsest beds when the flood was at maximum

height and violence; and the deposits now at or about their mouths contain, at various levels, such evidences of their perpetual activity. Others larger still, that now flow in broadly expanded valleys, would have lost, through the flood, their former pitch and torrential character, and have become for the last few miles comparatively feeble in transportation, capable of carrying and depositing only the finer materials; although arther up stream they might have continued to work as before. White River was an example. Such a large stream might owever have made coarse deposits at its mouth on the borders f the Connecticut, because of the concentration carried on by he drifting action of the current of the main river, and hrough contributions from ice-floes coming down the main ver or its tributary.

3. *The till the chief source of transported materials.*—The tribuary streams as well as the main river would have derived the hief part of their material for transport from the unstratified rift or till. For the glacier had already deposited it, or the arger part, and it lay over the wide surface of the country pen to receive the flowing waters, and ready for easy removal y them.

The *western* tributaries, Wells River, White River and the est, consequently, did not gather for transportation chiefly material from the Green Mountain rocks or those of other elevations about their sources, but the universal northern drift. Hence, the drift or till west of the river, while mainly from the northwest, came partly also—especially that over the western borders of the valley—from the region of the river and its head-affluents to the north and east of north; for the glacial scratches indicate movement of the ice of the valley in the general direction of the valley. Consequently, eastern and western tributaries and Connecticut river ice-floes may have carried in stones from the same northern and north-northeastern source.

Moreover, since the till consists ordinarily: of (1) stones, large and small, (2) earth or finely pulverized rock, and usually (3) of more or less clay, it supplied (*a*) clay for clay-beds, (*b*) sand for sand-beds, and (*c*) gravel and stones for coarser deposits. And, as the rising waters reached successively higher and higher till-covered levels, submerging ledges and the lower hills, and rising against the slopes of the higher, so clay-beds should have been formed from the clay of the till at various levels in the terrace formations, like the sand-beds and ravel beds;* but the extent of them should be relatively mall, or in proportion roughly to the clay in the till. The aterial of clay-beds may have come also from other sources;

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* The heights of many of the clay beds are mentioned beyond.

but there is a remarkable uniformity of characters in the clay beds, especially the higher, which seems to indicate that they had in general the same glacial source.

4. *Deposition. Terraces.*—As happens now, deposition should have taken place over the flood-grounds, either side of the channel, wherever the waters were more or less retarded, and over the bottom according as the velocity there allowed of it. Through these depositions, the terrace-formation and its terraces were made. Along the side of the swift-flowing stream, one or both, where coarse material was contributed by tributaries, the depositions may often have been of the coarsest kind, while 100 yards away they were of sand alone, as numerous examples illustrate.

With the increasing height of the waters, the flood-grounds would have received additions in height through new depositions. But this increase would have been *small*, *unless* the amount of material supplied for deposition were under constant augmentation so as to have kept pace with the increasing width of the stream, and most markedly so if for any long distance tributaries were absent or feeble carriers; and small, also, if the rise of the flood went on too rapidly to allow time for the slow work of transportation and deposition. The conditions for progress in the different parts of a valley would thus have been very diverse; and the diversity under them in the resulting height would have been greatly enhanced by variations as to breadth and depth, or receiving capacity, in the valley itself.

But meteorological phenomena have their long cycles; and these would have made the progress of the flood intermittent, causing times of slowly augmenting depth to alternate at long intervals with periods of nearly stationary level; and this circumstance might have afforded a chance for approximate uniformity of height in terrace-plains at certain levels. Such a long period of nearly stationary level might have given time for building up the deposits to a common height, that of the existing water level, under different rates of supply of material, over very wide regions. A greater height than the water-level is not generally produced in such cases because of the chiseling or abrading action carried on by the surface portion of the waters, and the fact that the surface is the upward limit of deposition.

In this way a terrace of nearly uniform height could have resulted; and, during another such intermission, another; and so on. Two prominent ranges of terrace-plains may be distinguished between the level of the modern flood-ground and that of maximum flood, one at 60 to 80 feet above modern low water and another 40 to 60 feet below the maximum.

According to the process described *the terrace-plains were* *formed during the rise of the waters.* This, though contrary to the views ordinarily held, and to an early opinion of the writer, appears to be true for the larger part. Yet many variations in the levels were no doubt produced by the abrasions and depositions attending the decline of the flood.

An argument against the making of the terraces of the valley by abrasion, forced on my attention through all my examination of the Connecticut Valley the past season, is afforded by the character of those plains throughout the valley. Except in the vicinity of tributaries, the lower terrace-plains consist almost uniformly of fine sand or sandy loam or clay, like the deposits beneath. Had the plains resulted through the removal of overlying deposits, that is, the grading down of higher terraces to the level of the lower, the action of the abrading waters would have generally left behind much gravel over the surface. Nothing like this ordinarily exists over the lower terraces.

Such a gravelly surface is however oftentimes found over the upper terraces, or within 50 feet of the highest terrace-level, partly as a consequence of the increased velocity of the river when the flood was approaching its maximum height, but to some extent, also, as a result of abrasion, which has resulted in depressing the surface and occasionally in making what look like broad channel-ways over it. It is of importance to note that such abrasions over the terraces by the waters flowing above them are wholly different in kind from the channelling and gouging done subsequently after the flood had subsided.

5. *The era of the glacier over the Connecticut Valley and of its melting continuous.*—Along the southern glacier limit in North America west of New England, interglacial epochs subordinate to the general Glacial period have been recognized. In the Connecticut Valley region, however, I have found nothing to indicate any such variations in the ice. The southern end of the valley, on the Sound, was at least 30 miles north of the southern line of the glacier, and hence the region was wholly within that of thick ice; and this is probably the reason for the absence of such evidence. While the facts about the White Mountains prove the ice to have had a thickness of at least 5,000 feet, the position of the New Haven region on the Sound favors the idea of a thickness not less than 750 feet. The situation of the valley with reference to the glacier, and the hilly features of the adjoining country hence explain why the valley deposits should make a continuous series from the lowest to the highest.*

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* The Champlain period is, as regards the glacier, a part of the Glacial period. But in view of the fact that a great physical change took place in the relations of the land and sea (as proved beyond), initiating the era of melting, it stands apart from the true Glacial period.

This last remark has no reference to the region of the White Mountains, where the ice may have been long continued, with the various phases of modern glacier-covered mountains, as urged by Professor C. H. Hitchcock in the first volume of the Report on the Geology of New Hampshire. Yet some of the transporting effects attributed by him to such local glaciers may, I think, be due to transportation by floating ice.

2. *A Channel-way a consequence of the flow in the flooded river.*

A channel-way exists as a consequence of the flow in all modern rivers. But, according to Mr. Upham, in his Geological Report on New Hampshire, the filling up of the Connecticut valley with stratified drift took place in the era of the melting, or the Champlain period, and the excavation of the channel and the making of the terraces, in a later era. He says, p. 15:

The material was "brought down by the glacial rivers from the melting ice sheet, or washed from the till after the ice had retreated;" and by this means "the open valleys became gradually filled with great depths of horizontally stratified gravel, sand and clay." "The modified drift thus increased in depth in the principal valleys through a long period, which may have continued until the last of the ice at the head of the valley and of its tributaries had disappeared." After this came the "Terrace Period," and during it, as the sentence following the last cited observes, "the rivers have been at work excavating deep and wide channels in this alluvium. The terraces mark heights at which, in this work of erosion, they have left portions of their successive flood plains." "In this way the Connecticut River, along the greater part of its course on the west border of New Hampshire, has excavated its ancient high flood plain of the Champlain period to a depth of from 150 to 200 feet for a width varying from one-eighth of a mile to one mile, leaving numerous terraces at each side."

On page 59, he says: "The formation of the terraces has taken place by excavation of a vast deposit that filled the valley level with these upper plains." On page 44: "When the river entered upon the work of excavating its present channel in the alluvium, the kame was a barrier which confined erosion to the area on one of its sides and protected its opposite side."

This hypothesis makes two great floods necessary to the results, one for transportation and deposition, and another for abrasion, when, in fact, one may have done both. In an ordinary river, the powers of transportation and abrasion are combined in their action; and a channel between flood-grounds exists because the transporting power is lessened on either side by loss of velocity. The channel and its allu [illegible] orders thus take shape together—the former through the la

To make the depositions extend up to a common level across a valley, or to approximate to this condition, either (1) the valley must have no outlet and the water therefore no current or velocity, so that contributions from the bordering slopes shall deposit equally, as nearly as possible, over the general area; or (2) the amount of transported material must be so large that transportation and friction use up the working force of the stream and reduce its velocity almost to zero.

Neither of these conditions was a fact in the flooded Connecticut. This is manifest from the varying nature of the deposits; and from the oblique lamination and flow-and-plunge structure characterizing the bedding in many parts of the valley. It is equally evident from the fine straticulation of the sand-beds. Had the stream been so clogged by its transported material as nearly to lose its motion, the assorting and stratifying action of flowing water would not have been exhibited so universally, and especially not in producing so generally a fine straticulate bedding of the sands and clays, the little layers of the beds but a fraction of an inch thick. This structure, like the same in the alluvium of the Nile, is proof of deposition by flowing waters, for each little layer required a separate special act in the flowing movement, or else successive conditions of supply and deficiency such as come by the changes of the day, or season, or year. From one end of the valley to the other there is this evidence in favor of the Connecticut's having been, through all the flood, a free-flowing stream, very much as now.

We are therefore safe in concluding that in the Connecticut valley the great stream which deposited the sands and gravel flowed with considerable velocity; and, if so, the making of a channel would have gone forward with the making of the depositions, the current where of greatest velocity locating the channel, and retardation either side by friction along with the attendant conditions of eddies locating the depositions.

Further, as is illustrated in all modern streams, a channel-way should have steep sides. The present pitch of the terrace-fronts toward the river, 35° to 42°, corresponds to the angle of rest in sliding gravel or sand when dry or nearly so. However steep the fronts at their formation, the retreat of the waters at any time would have left them to this treatment of gravity, whether formed as the flood rose, or by abrasion along the riverward margin of the terraces while it was declining.

The channel-way being thus the result of the dynamics of flowing water, no ice was needed along it, or "kame" ridges on its sides, to fix its shape or limits.

The extensive terrace-formations of the Sacramento River valley, in California, among the first studied by the writer (a little over forty years ago).* were deposits far away from the region of ice; for the glacier of the Sierra Nevada, according to Whitney, and also Brewer, did not reach down within 2,000 feet of their level. Yet they have nearly identical features with those of the Connecticut. This is true even to the greater coarseness, in many parts, of the upper deposits. The route of the party I was with, after reaching the valley of the Upper Sacramento, just south of latitude 40° 45′, led us for fifteen miles over a high terrace-plain covered thickly with stones one to three inches in diameter, much to the annoyance of our already jaded horses. The channel-way, or open space between the high terraces of the east and west sides of the river, the terrace-plains, the terrace-front of 40° and sometimes 90° through undermining abrasion, were peculiar only in their wonderful extent.

The *width* of the channel-way has other determining causes besides velocity: such as the amount of transported material for deposition, and the form of the enclosing valley, as already explained. Along the Hudson River below the Highlands, the waters at the time of the great flood were 75 to 95 feet above the present level; and yet, owing to the nearness of the rocky hills, the channel-way was not a fourth wider than the present river; for the higher terraces rise almost immediately from its banks. On the other hand, the channel-way of the Connecticut at Hartford, Conn., had a width of 1 miles; owing partly to the low level of the region, and largely to the long trap-range on the west, shutting out tributaries and their contributions of sand and gravel. The Farmington River, which comes from that direction through a cut in the trap range, and reaches the Connecticut half a dozen miles north of Hartford, left a large part of its transported material west of the range in the Farmington Valley, where it made terraces over a hundred feet in height.

3. *Normal upper terraces.*

Professor Edward Hitchcock, finding that the terraces of the Connecticut about the mouths of tributaries were much the highest, designated them, in his "Surface Geology," "delta-terraces;" and Mr. Upham, adopting the view, represents them as terraces above the level of the "highest normal terraces" of the valley. The difference in height between the two kinds of terraces, the "highest normal terraces," and the "delta-terraces," along some parts of the Connecticut, are stated by Mr. Upham to be 40 to 50 and sometimes 100 feet.

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* October 11, 1841, on a land expedition from the Columbia River to San Francisco, connected with the U. S. Exploring Expedition under Captain Wilkes. See my Geological Report of the Expedition, 756 pp. 4to, 1849, pp. 659–674; and for an abstract, this Journal, II, vii, 257, 1849.

I cite here Mr. Upham's explanation of the delta-terraces and their relation to the "highest normal terraces," from page 16 of his Report. "Upon entering the large valleys, tributary streams of comparatively narrow channel and rapid descent frequently formed extensive deposits in the Champlain period, similar in material to the flood-plain of the main valley, but having a greater height. Sometimes these *deltas*, being partially undermined, form conspicuous terraces a hundred feet above the *highest normal terrace*, which is the remnant of the river's continuous flood-plain. The deposition of the modified drift of the main river was usually, not always, to the same level across the valley. The increased supply from tributaries was sometimes a temporary barrier, damming up the waters of the main valley above; and the current could then deposit its sediment principally upon one side, making the highest normal terrace quite different in elevation."

To understand this explanation, Mr. Upham's idea as to the filling of the valley with deposits before the making of the channel-way, considered on the preceding page, must be in mind. If the making of the channel-way and terraces went on together, as appears to have been the case, some other conclusion, both as to the "delta-terraces" and the "highest normal terraces," must be found. The terraces of the latter kind, in any part of the valley, are rightly the highest there observed by Mr. Upham, with the exception of the "delta-terraces;" but if the conditions in the drainage area of the Connecticut valley were those of a flooded river with simultaneously flooded tributaries, the so-called "delta terraces," or terraces at the mouths of tributaries, may mark the height of maximum flood in the main river. The ramifying streams would have constituted a continuous range of waters, like a river and its tributaries at the present time, and would have made a continuous system of deposits. The large tributary would have entered the Connecticut with no greater pitch perhaps than that of the Connecticut itself; while smaller streams might have had a somewhat higher pitch according to the slope of the surface beneath, or the amount of sand and gravel with which the waters were loaded; a pitch of *ten* feet a mile under the last-mentioned condition would be large, of *fifteen*, very large, and of *twenty* feet, improbable. Only in case a tributary had ridges about its mouth so as to favor the formation of a dam, or had had its way obstructed by a barrier of ice, would terraces of abnormal height and pitch have been made. Otherwise the waters of the Connecticut would have extended into the mouth of the tributary, the one blending with other. The terraces of the latter, the so-called "delta-terraces," might thus have been part of the terrace formations of the main river. And such "delta-terraces," especially those that project out into the Connecticut valley so as to terrace it for some distance, may be and generally are, the best indicators of maximum flood-level to be found, the true highest normal terraces; because, as already explained, the supply of detritus for terrace-making was there the greatest. Were the waters so clogged by the material under transportation as to flow like mud, the angle of pitch might be even as high as 15 or 20 degrees. But the stratified and straticulate structure of the deposits proves that such a condition was of rare occurrence.

From this obvious relation of the tributary terraces to those of the main river it became of the highest importance to ascertain whether the "delta-terraces" of the different tributaries might be safely taken or not as the highest normal Connecticut terraces for the part of the valley in which they occur, and the study of this point was one of the prominent objects before me in my examination of the Connecticut valley. I found, in nearly every case investigated, that the outer part of the tributary terraces would have been within the range of the flood waters of the Connecticut; so that, while the tributary was pouring in its abundant detritus, the main river would have been distributing and leveling it. This was so with Oliverian Brook in Haverhill, where it opened on the Connecticut. The normal terrace of the Connecticut, at the mouth of this stream, is stated by Upham to be only 83 feet above low water in the river, while this brook opens on the valley with a terrace over 200 feet in height. That this brook should have held its waters up to this great height and made a terrace at that level, when those of the Connecticut were more than 100 feet below, is not possible, unless the side of the Connecticut against the mouth of the stream were blocked with solid ice; and this condition is shown by other facts not to have existed. The facts are similar in the case of the "delta-terrace" of Israel's Brook in Lancaster; of Jacob's Brook in Orford, five miles north of Thetford; of Eastman's Brook in Piermont; and of most other delta-terraces.

The true *normal upper* terraces of a valley are *those that register the same high flood-level.* They are not always easy to be distinguished, because of the inequalities in height from unequal deposition or subsequent abrasion; but with careful comparisons good general results can be reached.

The range of *normal* upper terraces along a valley should have a pitch down stream corresponding in a general way with that which the river had at the time of the flood. Mr. Upham's Report states that the upper terrace of the Connecticut valley becomes *suddenly lower* above Thetford, where the long "kame" ends; is reduced at Ely, two miles above Thetford, from a height above low water in the river of 140 feet to that of only 55 feet; that it has this low level, continued northward, with little change, for eighteen miles, or more than half way to the mouth of the Passumpsic; and that at Haverhill, seventeen miles north of Thetford, the "highest normal terrace" is 83 feet above the river, while twelve miles to the north it is 135 feet. But, taking the terraces at the mouths of tributaries as marking the flood-level along this part of the valley—the so-called "delta-terraces" of Oliverian Brook, Jacob's Brook, Eastman's Brook and others—and then the low terraces referred to become simply the lower terraces along a part of the valley in which the highest normal terraces are wanting, except at the mouths of tributaries.*

With regard to the high terrace-plain of Haverhill there are other facts besides those connected with the terraces of Oliverian Brook; and these are presented on a following page.

[To be continued.]

ROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXIII, MARCH, 1882.]

. XVII.—*The Flood of the Connecticut River Valley from the elting of the Quaternary Glacier;* by J. D. DANA. With late II.

[Continued from page 97.]

4. *Dimensions and velocity of the flooded Connecticut.*

N the preceding pages it has been shown that during the
of the melting of the glacier the Connecticut River and its
utaries participated together in the rising flood and in the
k of transportation and deposition; that the tributaries
ught in the chief part of the materials for the terrace-forma-
; and that the main stream left its best registerings of high-
er mark in the deposits about or near their mouths. When
flood was at its height, the Connecticut was one continuous
m, hurrying seaward, as it is, though in a more moderate
, during a modern flood.

e may now seek to determine approximately the dimen-
s and velocity of the river when at maximum flood, taking
he several points in the following order:—(1) the height of
waters; (2) the mean depth; (3) the mean width; (4) the
n slope; (5) the velocity. As to the height along the val-
the facts are obtainable with a near approach to accuracy
n the height of the normal upper terrace. But for the
th and width the data are less satisfactory; and for the slope
velocity, or the height of the water surface with reference
ea-level, on which slope and velocity depended, the evi-
ce is still more uncertain.

. MAXIMUM HEIGHT OF THE WATERS ALONG THE VALLEY.—
ore the flood had made much progress, the level of the
r may have been the same with the present low-water level,
elow it. And, between this condition and the end of the
in the waters, there were successive levels along the valleys
some perhaps of long duration. There are no satisfactory
ns of determining the height either of the lowest or of any
owing stage, excepting the last—that of maximum flood.

Vith regard to the level of maximum flood we take the
s afforded by the heights of the normal upper terraces in
different parts of the valley. To show these heights at a
nce and the continuous line of the water-surface I have
tted them for the several points of observation, together
h the levels of low water and mean tide, so as to make a
ion of the flooded valley and stream; and this section is
sented on Plate 2.

he plate contains, above the section, in figure 1, a map of the river and its vicinity on a scale of 18 miles to the inch (or 1½ miles to the line), which extends from the village of Columbia, toward its source (about 28 miles from the more southern of its head lakes called Connecticut Lake) to Long Island Sound. The position of the western outliers of the White Mountains is seen to the east of Wells River and Haverhill. The Green Mountains, on the west, are too distant to be included. The section of the flooded stream just referred to is on the same scale as to length measured along the valley (not the river) but extends only to Stratford Hollow, 45 miles from Connecticut Lake, on account of the northeastward bend in the more northern part of the valley. The vertical scale of the section is 300 feet to the inch, or 25 feet to the line. In this section the longitudinal line AS indicates mean-tide level; BS the level above mean-tide of modern low water in the Connecticut, the figures under the line giving the same in feet for the places mentioned below; and CS′, flood-level when the flood was at or near its maximum-height. The figures directly below CS′ give the height of the surface above mean tide at each of the places stated, and those reading vertically, the difference between modern low-water level and the highest flood-level.

For the part of the section north of the Massachusetts line the levels for mean tide, low water, and maximum flood have been taken mostly from Mr. Upham's very valuable Report. But with regard to the particular terraces that mark the maximum height of the flood I diverge from him in many parts widely; and in a few other points I have depended on my own examinations. Some of these divergences I here mention in order that the nature of the changes introduced may be understood.*

The height of the "highest normal terrace" at Lancaster, according to Mr. Upham, is 30 feet above low water in the river. But the so-called "delta terrace" of Israel's Brook, just above the village, having a height of 75 feet according to his measurements (and my own), borders strictly the Connecticut River valley and was, beyond question, levelled off by the flooded river. It is the highest terrace at the place. Four miles north, at the mouth of Gaskill Brook, Mr. Upham's map has a terrace 100 feet above the river, which also borders the Connecticut valley; and 15 miles farther up the valley (3 miles above Stratford Hollow), there is a terrace 130 feet above low water. The actual height of flood-level at Lancaster and above was certainly up to the 75-foot terrace-plain, and probably up to the 100-foot, if not the still higher

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* In the measurements of the heights of terraces I have used a hand-level. As the method is less exact than that employed by Mr. Upham, I have always in any remeasurements accepted Mr. Upham's results.

In speaking of a terrace, I often use the term *terrace-plain* for the plain that makes the top of the terrace, and *terrace-front*, for the front slope of the terrace, the angle of which is often 40° to 42°.

130-foot; it is made 100 feet on the chart; while the 130-foot level is indicated by a dotted line. Along the Fifteen-mile Falls, between John's River and the mouth of the Passumpsic, the region of the upper falls, according to Mr. Upham, is without regular terraces; but that of the lower, below Lower Waterford, has hills and terraces of stratified drift which reach in some places a level of 200 feet above the river. So great a height here favors the view that the 130-foot level at and above Lancaster is the most nearly right. My personal observations in the valley beyond Barnet were limited to the single locality of Lancaster.

At Barnet, in Vermont, three miles below the termination of the Fifteen-mile falls, the "highest normal terrace," according to Mr. Upham, is 148 to 166 feet above low water in the river. A large upper terrace west of the village off the mouth of Stevens' Brook, (a "delta terrace" of Mr. Upham,) I found to be 198 feet above the same level; and the small uppermost plain, 225 feet. It was manifest that these plains were not distinctively terraces of Stevens' Brook; for the brook now flows over stratified drift and between bluffs of it, 70 to 95 feet below the level of these plains; and it could not have worked at terrace-making at these high levels, except by the help of the Connecticut waters. That at least the lower of the two terraces above-mentioned was strictly a Connecticut River terrace is proved by the occurrence of it two miles north along the Connecticut valley (near the mouth of the Passumpsic) with a height of 198 feet according to Upham (p. 60) above the river at Barnet, or 190 above the river abreast of the terrace. The material of the Barnet terraces is mostly loam with fine sand in straticulate beds up to the 150-foot level; and at 164 feet, just north of the village, I found a clay-bed.

At Wells River, a "delta-terrace," 263 feet above low water in the river, was found to be the true normal upper terrace of the Connecticut instead of the terrace so-made by Mr. Upham having a height of only 123 feet.

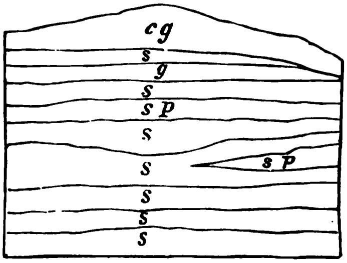
At Haverhill the "highest normal terrace" of Mr. Upham has a height, as he states, of only 83 feet. But the true normal upper terrace is over three times this height, as is shown by the position and extent of the large Haverhill terrace-plain as well as the so-called "delta-terrace" of Oliverian Brook.

The terrace-plain on which the village of Haverhill is situated has great breadth, and continues along the Connecticut for two miles south of the village. Its height above low water in the river, by my measurement, up to a point in the street near the hotel, is 259 feet, and it rises eastward to 273 feet. Its surface consists of sand and sandy loam with some small pebbles, but becomes more stony toward the hills.

Mr. Upham alludes to the plain, but excludes it from the true terraces, stating that it is "a terrace-like area of *till.*" He says that "at about one-fourth mile southwest from Haverhill village a gully recently made on a previously smooth slope, at a height about 175 feet above the river and 75 feet below the village showed 15 feet of modified drift resting on till." What I found at the locality here (as I suppose) referred to, was a till-like deposit resting on the stratified drift. At the time of my visit in June last, there were three good sections of the terrace-formation along the road that leads north and west from the high village plain or terrace to the river-border plain, and in each the deposits were chiefly *finely-straticulate sand-beds.* In the *upper* of the three sections, exposing to view the higher 20 feet of the formation, the deposits were found to consist of sand and fine gravel well bedded, and in part obliquely laminated.

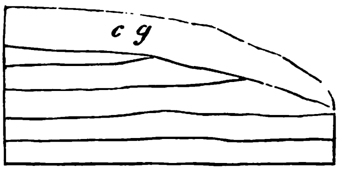
Lower down the road, 30 to 60 feet below the top of the plain there was a *second* section, exposing about 30 feet in height of layers of finely straticulate sands, with some that were pebbly. This stratified drift had a capping of cobblestone material which lay somewhat unconformably over the beds. The character of the section is shown in figure 1; the sand beds are lettered *s* in place of being dotted or lined, because the very delicate straticulation would be misrepresented in any engraving unless the figure were made inconveniently large. The cobblestone capping, *c g*, cuts obliquely the upper of the stratified beds.

1.



Layers of finely straticulate sand (*s*) and sand and fine pebbles (*sp*) overlaid by coarse gravel, till-like (*cg*).

2.



Section 3. Layers of sand, with some of fine gravel, finely bedded, overlaid by a till-like deposit (*cg*).

The *third* section, a few rods farther down the road, carries the section of the terrace-formation down from 65 to 90 feet from the top, or more than half of the way to the 83-foot terrace; and this was probably the position of the gully mentioned by Mr. Upham as situated about 75 feet below the village. Its beds were like those of the preceding section. The capping of stones and earth, seen in the former section, was continued here, and had greater thickness with larger unconformability to the stratified beds beneath; and some of its stones were angular and two feet in diameter. Figure 2, representing the upper half of this exposure, shows the position of this stony deposit, *c g*, in relation to the beds beneath.

This till-like deposit is thus a superficial mass lapping down the slope, quite independent of the terrace-formation; and it is therefore of subsequent origin. It was probably dropped by floating ice. The Oliverian Brook, which here enters the Connecticut, comes directly from the southwestern part of the White Mountains, —Mt. Moosilauke, 4811 feet high and not a dozen miles off, being its source (see map), and other peaks, 2000 to 2500 feet in height, bordering its course.* The section at the time of Mr. Upham's examination of it must have shown the till-like deposit but not the beds beneath.

On an ascent of the terrace half a mile farther south I found evidence of sand-beds and fine gravel, but saw nothing of the till-like capping; and it was evident that the latter was a local deposit. Neither did I observe evidence of it near the village over the top of the plain.

At Piermont, the "delta terrace" of Eastman's Brook, 258 feet above low water level, is so situated evidently with reference to the Connecticut valley that it should be taken as the normal upper terrace, instead of the 78-foot terrace made the "highest normal" by Mr. Upham; and at Fairlee, a "delta terrace" of Jacob's Brook, having a height of 247 feet, is the upper terrace, instead of a 57-foot terrace so made by Mr. Upham.

In the north part of Norwich, the kame, according to Mr. Upham, has a height of 189 to 224 feet above low water in the river; and the mean of these extremes, 207 feet, is not too high for flood level, and this is taken as the height instead of the 159-foot terrace of Mr. Upham.

In Hanover, the Mink Brook "delta terrace" carries the height up to 207 feet above low water in the river.

Between Hanover and White River Junction—four miles apart —there are, near midway, falls of 40 feet.

At White River Junction, the southwest kame warrants carrying the level up to 213 feet at least, in place of 177; and a terrace to the west of it makes the full height, as I found, 242 feet. The correctness of this higher level is sustained by the height which Mr. Upham gives on his map for the upper terrace and kame three miles south, in North Hartland, namely, 242 feet, and nearly by that of the "delta terrace" of Lull's Brook, 227 feet high, four miles farther south in Hartland.

In Windsor, I made measurements up to the high plain west of the village, and found it 216 feet above low water in the river, which is the height taken in place of the 196-foot terrace. The material of the terrace was fine sand and loam, but slightly pebbly in the upper portion. It is a terrace of Mill Brook, but not less so of the Connecticut.

These examples are sufficient to explain the course I have pursued.

For the height of flood-level in the part of the valley passing through the State of Massachusetts I have used some of the measurements of Professor Edward Hitchcock, and for the Springfield region, the survey of the Springfield City Engineer, as in a former paper.* I have personally made levelings in Holyoke, Willimansett, and South Hadley. It was my purpose to have made further observations in the State, but finding that Professor B. K. Emerson, of Amherst College, was engaged in a thorough study and mapping of the terraces, I gladly left the subject in his hands.

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* Professor C. H. Hitchcock observes, in vol. i of the Geological Report of New Hampshire (p. 217), that the Oliverian Brook in Haverhill may be expected to show signs, through boulder deposits, "of a local glacier descending the west flank of Moosilauke."

The height of the very extensive upper terrace of western Northfield, the town adjoining New Hampshire, I have taken from Mr. Upham, his map covering this Northern Massachusetts town; he gives it at 198 to 213 feet above low water in the river. Although the terrace borders most obviously the Connecticut valley, he speaks of it as a tributary's terrace, and takes for the "highest normal terrace" one only 128 feet high above the river. The true upper terrace extends to Gill; and a corresponding one on the eastern side of the Connecticut, but little lower, continues with small interruptions all the way to Miller's Falls.

For the height of low water level in the Connecticut Valley, between Holyoke, in Massachusetts, and Hartford, Connecticut, I have used the section made in connection with the very exact survey of General Ellis, making part of the Report† of General Warren for the year 1878. The height for the river above Holyoke has not yet been accurately determined. In the section, the height at the top of Turner's Falls is made 180 feet, and at the foot of the rapids, 120 feet.

In the Connecticut part of the section, the heights are, with one exception, from my own levelings. My former measurements have been repeated, in order to be able to refer the heights to mean-tide level, and others have been made.

The extensive terrace east of the Connecticut, which commences 8 miles north of Springfield and has a width in Massachusetts of 2 to 6 miles, with an average height of 180 feet above mean tide, extends as many miles into Connecticut, and east of Thomsonville spreads eastward half a mile beyond Hazardville, or 4½ miles, with a height of about 160 feet. It is in general a plain of unfertile sands, but fine-pebbly on some higher portions. It seldom rises to the level of maximum flood. Just south of Thomsonville, this upper plain appears about the isolated Enfield ridge, at a height of 214 feet. Two miles west of the Connecticut, nearly opposite the latter place, it has full height, 215 feet, about the isolated ridge of Suffield village. The material is coarse gravel. A northern portion of the Suffield ridge is 10 feet higher and is of coarse cobblestone material, and may be till.

Northwest of Hartford, the upper terrace is well defined half a mile from the gap through the trap for the Farmington River, and has a height, by aneroid, of 210 to 215 feet. The plain in the vicinity of the Manchester depot, on the east of Hartford, is about 200 feet in height.

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* Southern New England during the melting of the Great Glacier, this Journal III, x and xi, 1875, 1876.

† Annual Report of the Chief of Engineers for 1878, Appendix B 14. Report of the surveys and examinations of the Connecticut River between Hartford, Conn., and Holyoke, Mass., made since 1867, by Brevet-Major General G. K. Warren, Major of Engineers, U. S. Army.

South of Hartford, east of the Connecticut, in Glastenbury, a broad terrace rises abruptly from the river and spreads two to three miles eastward, with a height of 170 to 190 feet. Two miles north of Middletown it is reduced to a broad shelf against the eastern hills, a mile or more from the river, and has a height of 186 feet above mean tide east of Gildersleeve's landing.

At Middletown, where the river turns eastward to pass the Narrows, the waters spread 2 to 4 miles west of the Connecticut. At Rock Falls, and just beyond, the terrace deposits have a height of 193 to 199 feet above mean-tide; and at Pine Grove Cemetery the wide plain is, according to an aneroid measurement by Professor Wm. North Rice, of Middletown, 199 feet.

The facts make the maximum height at Middletown probably between 193 and 199 feet.

Nearly two miles southwest of Middletown, just east of the Haddam road, stratified sand and gravel make the upper part of a hill which is 235 feet high above mean tide. If a part of the terrace-formation, it would make the maximum level of the flood and of the Middletown dam 40 feet above the height just mentioned. But it has a capping 3 to 4 feet thick of coarse unstratified material containing some scratched stones, and is probably of earlier origin. The hill stands between higher, rounded, till-covered hills on the west and east, with low, marshy land adjoining, and between a wide region of lower land to the south (the Johnson Lane district), and the valley of the Connecticut to the north and northeast; and if waters were above 200 feet over the region, they would there flow across to the Connecticut. The conditions of origin are not easily explained.

The height of the line of flood-level in the section on Plate 2 is in several cases below that which the highest terrace-plain seems to authorize. Thus, at Haverhill, the upper terrace-plain has for its highest part to the eastward 673 feet, 10 feet above the height in the section; at Brattleboro, where 410 feet is taken for the height of flood-level, a terrace occurs according to Upham's map, of 425 feet; at Dummerston, 5 or 6 miles north, there is one either side of the stream of 420 to 440 feet; in Northfield the terrace rises toward the hills 15 feet above the level taken for the upper level; and so in several other cases. It is quite common for a terrace-plain to rise in level above the average height as it nears the hills: and as this may come in part from material carried down the slopes at the time of the flood and washed over the surface raising it above true flood-level, I have not generally taken the extreme height thus afforded. Moreover the terraces of tributaries often rise rather rapidly where within a confined valley, owing to the great amount of transported material. I have sought to be rather under the true height than above it in all judgments. It is quite possible, however, that a more exact study of the terraces will place the flood-level higher than I have done; certainly higher, I think, rather than lower.

The section gives an impressive idea of the greatness of the ancient flood. The river had, as it shows, two great falls in its course, one, the Fifteen-mile Falls to the north, below Lancaster, the other a twenty-five mile fall on the way to the Sound from Middletown, Connecticut. It took its full magnitude west of the White Mountain region, after its junction with the Passumpsic, one of its two chief sources, and after accessions from its other head waters, Stevens' Brook and Wells River on the west, and the Ammonoosuc River and Oliverian Brook on the east. At North Haverhill the height of the water above modern low-water level was at least 250 feet, and its width exceeded two miles; and it was nearly or quite 200 feet above the same level at Middletown in Connecticut, 172 miles south of Haverhill and 26 miles in a direct line along the valley, from the Sound. The diminution in depth southward was evidently a consequence of the increasing width, especially after entering Massachusetts.

The Fifteen-mile falls were long rapids over a nearly continuous slope of coarse till, showing abundant bowlders but with scarcely any exposures of solid ledges.* The falls below Middletown began in a plunge over a dam 190 feet high above modern low water, that was formed at the Narrows—a cut, but 650 feet wide in its lower part, through a high rocky ridge of crystalline schists and enormous granite veins. Below the dam the descent in the waters is registered in the terraces of the valley (see section on Plate 2); and it is shown thereby to have been gradual and not a vertical plunge. The dam was probably an ice-dam as explained in a former paper.† Above the dam the waters spread westward over the Middletown region to a distance from two to four miles, covering the tops of some prominent hills. Yet those of the hills that are within one to two miles of the river are mostly free from stratified drift and terraces, and have instead rounded surfaces and a deep covering of till; and it may be that this scoured condition was produced by the violent rush of the waters at the final destruction of the ice-dam.

To enable the reader to compare the ancient with the modern floods of the Connecticut, a section of the latter from Holyoke to Long Island Sound is given on the general section. For the part from Holyoke to Hartford it is taken from the section published in General Warren's Report as the result of a series of careful measurements by General Ellis. For the height at Middletown I have taken the height of the highest modern floods at that place, 25¾ feet. These high floods of modern times are largely dependent for their height on obstruction by ice at the Narrows, like those of more ancient time.

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* Report of Mr. Upham, p. 24.

† This Journal, III, xi, 178, 1876.

The comparison which may thus be made can give but a feeble idea of the actual contrast. The modern stream in its greatest floods retains still its tortuous course and abrupt bends, and the great width it takes in some parts is made by the spreading of only a thin layer of water over wide flood-grounds. But in the time of the great flood, the river for the most part rose above such obstacles, took the wide valley for its channel, and had an almost unimpeded course on its way to the ocean. In figure 4 on Plate 2, an enlarged map of the river-valley from Wells River to a point below Bellows Falls is given (from a map of the Atlas accompanying the New Hampshire Report). It shows by the dotted line either side, the east and west limits of the terraces, and thus indicates something of the extent to which modern bends were absent.

On the other hand the height of the flood as exhibited in the section is greatly exaggerated compared with the length—though hardly so if measured by the impression which the high terraces make on the mind of an observer. To aid the reader in eliminating this exaggeration, a section of a small portion of it with the natural pitch is given on the plate in fig. 3, below the general section of the river. This section represents the "Fifteen-mile Falls," along the twenty miles between the mouth of the Passumpsic and St. Johns River. According to Mr. Upham's Report, the whole fall in the 20 miles is 370 feet; the upper fall, 156 feet; the lower, 183 feet; and the descent between the two falls, 31 feet.

Some additional exaggeration is made apparent in the course of the following discussions.

From the facts presented in the section and others connected with the Connecticut valley and its terraces, we may obtain approximate results with regard to the *mean depth* of the flooded river, its *mean width*, the *mean slope* or pitch of the stream, and its mean *velocity*.

2. MEAN DEPTH.—In seeking to ascertain the mean depth of the flooded river at any place, we cannot rightly measure down to modern low-water level. For over the bottom of the valley, there is very commonly a wide terrace 60 to 80 feet above low-water; and, when the flood was far advanced, this terrace-plain may have extended across the narrow channel of the modern river and obliterated it. On account of the wide extent of this lower terrace, it appears to be necessary to deduct 60 to 80 feet from the whole height of the flood in most parts

of the valley: and for the sake of an estimate and not an over-estimate, 75 feet may be the amount deducted.

According to the section, the height above modern low-water level at Haverhill was about 260 feet; and this, diminished by 75, gives for the depth 185 feet. So we obtain for Hanover and White River Junction, if the height of the intervening falls be divided between them, 225–75=150 feet; for Windsor, 216–75=141 feet; for Brattleboro, 210–75=135 feet; for South Vernon, near the border of Massachusetts, 207–75=132 feet.

We may thence take for the average depth north of the Massachusetts line, 140 feet. The depth on the southern boundary of Massachusetts obtained by the same method would be 125 feet, and at Hartford in Connecticut, 125 feet. But the width is so much greater after entering Massachusetts, that it is quite certain, as already stated, that the less depth is more than balanced by the greater width.

3. MEAN WIDTH.—In order to obtain an approximation as to the mean width of the flooded stream between Wells River and the Massachusetts line, we may review, for a few localities, not only the width (which I take from Mr. Upham's map), but also the areas of cross-sections.

At Haverhill, the highest normal terrace of the east side rises nearly to its full height, 263 feet above low water level, directly from the lower terrace-plain of 83 feet. The width of the channel-way on the map, above the 83-foot terrace, is 4,000 feet. Taking for the depth of water 263−83=180 feet, the area of the cross section, with this width, would be 720,000 square feet.

Between northern Orford and Fairlee, 8 miles south of Haverhill, the higher terraces are wanting. Taking for the width only that covered by the valley deposits, that is, the low terraces—it is about 3,300 feet—which is too low, because there is no high terrace to mark the actual width, and the low terraces referred to are only 55 feet above low water. The height of the flood as given in the section, Plate 2, is 252 feet; thence, with the depth (252−55=) 197 feet, and with 3,300 feet as the width, the area of cross-section is 650,000 square feet.

Where the valley passes Norwich and Hanover, the most prominent terrace has a height of about 150 feet above low water in the river, while the upper one, marking flood limit, is 210 feet. The channel-way has hence a narrow *lower*, and a wide *upper* section. For the width of the former, I have measurements obtained for me by Prof. R. Fletcher, of the School of Civil Engineering at Dartmouth College. The measurements were taken between points half-way up the steep terrace-front.

600	feet below	the bridge crossing	the river,	width	1,980	feet.
400	feet above	"	"	"	1,350	"
800	"	"	"	"	1,270	"
2,500	"	"	"	"	1,000	"

The mean of the above numbers is 1,400 feet. At the last of the localities, the river has on its west side high rocks and therefore no terraces, and the bottom terrace is only 30 feet above low-water level. This number should, therefore, be thrown out, the small width having probably been compensated for by increased velocity. In this case the estimated mean width would be over 1,500 feet.

For the width of the upper section of the flooded stream, or that above the level of the 150-foot terrace, we have the interval between the highest terraces of the two sides of the valley in the line of the villages of Hanover and Norwich, 8,000 feet; and on a transverse line 2,500 feet below the bridge (see above), 4,000 feet. The mean between the two is 6,000 feet. To obtain the area of a cross section we have then 1,500 feet for the mean width of the lower section of the flooded stream, and 6,000 for the upper. For the depth of the lower section, we deduct from 150, 47 feet, this being the height above low water of the higher of the bottom terraces, and obtain 103 feet; and for that of the upper, 210 − 150 = 60 feet. The area of the whole cross-section, afforded by these numbers, is 514,500 square feet. The falls of 40 feet in the river, two miles below Hanover, suggest a good reason for the little height of the lower terraces.

Above Brattleboro, the mean width, as nearly as we can obtain it from Mr. Upham's map, is 5,000 feet. The depth, deducting 75 feet for the lower terrace, is 135 feet; and this gives for area of cross section, 675,000 square feet. At the narrowest part 3 miles north of Brattleboro, the width of the channel-way is 3,500 feet; but this is so only for a short distance, and the lower terraces here have a height of but 35 to 50 feet. With this width and deducting only the mean between 35 and 50, or 43 feet, for the lower terrace, the area of section is about 585,000 square feet.

From these results, although not based on accurate measurements, we may conclude that the area of cross-section for the Connecticut, between Wells River and the Massachusetts line, averaged *at least* 560,000 square feet, and hence that the mean width, if 140 feet be taken as the mean depth, was probably not less than 4,000 feet.

4. MEAN SLOPE.—We may *first* deduce the slope or pitch on the assumption that the land and ocean had their present relations as to level; and then, *secondly*, consider the evidence as to these relations having been different from now, and *finally* make other calculations in accordance with the conclusion reached.

A. *Mean slope of the river in case the land and ocean had their present relations as to level.*—Supposing the land and ocean in the era of the flood—the early part of the Champlain period—to have had their present relative level, the slope of the stream may be taken directly from the section on Plate 2, the figures along the upper line giving the height at different localities along the valley, and those by the lower lines the distances as *measured along the valley* (taking no note of the turns in the river) between localities, on a scale of a twelfth of an inch to 1½ miles. We thus find for the slope:

	Distances in miles.	Slope per mile.
Haverhill (655 ft. flood-level) to Windsor (520),	41	3·3 feet.
Windsor (520) to South Vernon, Vt. (396),	49	2·5
South Vernon (396) to Springfield, Mass. (240),	44	3·5
Springfield (240) to the Middletown Narrows (195),	38	1·2
Narrows (195) to Long Island Sound,	26	7·4
Haverhill (655) to the Middletown Narrows (195),	172	2·7
South Vernon (396) to the Middletown Narrows (195),	82	2·5
Haverhill to the Sound,	198	3·3
South Vernon to the Sound,	108	3·6

From the above it appears that, except for the dam at the Middletown Narrows, the mean slope from Haverhill to the Sound would have been 3·3 feet per mile, or the same as from Haverhill to Windsor. But, owing to the dam, the mean slope to Middletown is but 2·7 feet, while below the Narrows it is 7·4 feet per mile.

B. *Mean velocity.*—To obtain the velocity, we have the data above deduced for the mean width, depth and slope of the flooded river.

Another element required is the amount of resistance from bends and obstructions in the stream. It is fortunate for the calculations that the Connecticut valley follows a remarkably straight north-and-south course. With the water raised 200 feet and more above modern low water and a width thereby averaging nearly a mile along the course north of Massachusetts and more than this south, the bends are only those of very large curvature, which would not affect greatly the velocity of a rapid stream. On the map of the river and valley between Wells River and Bellows Falls, figure 4, Plate 2, the band covered by the deposits, indicated by the dotted outline, shows that the waters made *nearly a straight stream.* The map is somewhat short of the truth, since the upper terraces are absent in parts of the valley and particularly so for the narrower part along from Ely to Piermont. Only a map that gave on each side of the valley the contour-line corresponding to the height of maximum flood, and also the limits of the channel-way as marked by the inner limits of the highest terraces, would show fully the degree of straightness.

Below Windsor there is a prominent obstruction in Mount Barber, an elevation in the direct course of the stream and a mile wide; but there was abundant room for the river on either side of it. Another obstructing mass of ledges probably existed just south of Turner's Falls southwest of the mouth of Miller's River, in Massachusetts, ten miles south of South Vernon, where the Connecticut river makes a westward bend of six miles to Greenfield. This *probably existing* "mass of ledges," is now beneath the terrace formation, the top of which is the elevated plain between Montague City and Miller's river; and its existence at no great depth beneath the plain is inferred from the terrace deposits—on the ground that these are an indication of slackened flow in the waters. The flooded river passed both along the east and west sides of these obstructing ledges, as well as over them at highest water. After passing this place, the river at highest flood had an open and almost straight way to Middletown, which was nowhere less than 4,000 feet in width, though narrowed at Mt. Holyoke, Enfield Falls and Glastenbury.

Whenever a careful topographic survey of the Connecticut valley shall have been made, which shall lay down throughout it contour-lines corresponding to the maximum flood-level, it may be possible to arrive very nearly at the amount of resistance produced by the flexures. At present it is not possible to reach any accurate estimate; and the best that we can do is to use a diminished width for the basis of the calculations and make a further allowance by estimate. The results with regard to the velocity are hence obtained below for the river with a breadth of 2,500 feet, as well as with that of 4,000 feet.

The formula for the calculation of the velocity here employed is that given by Humphreys & Abbot for large rivers in their admirable Report on the Mississippi River, numbered 41, on page 312. It is applicable strictly to a limited portion of a large river without bends. It is as follows:

$$v = \left([225 r_{,} s^{\frac{1}{2}}]^{\frac{1}{4}} - 0{\cdot}0388 \right)^2$$

in which v is the velocity sought; s, the sine of the slope; and r, the mean radius = area of cross-section, a, divided by $p+W$, or the length of the wetted perimeter (p) *plus* the width at surface. In the general formula, the sine of the slope $= s = \frac{h'}{l}$. l = length of limited portion of the river. $h = h_{,} + h_{,,} =$ difference of level of the water-surface at the two extremities of the distance l, in which $h_{,}$ = the part of h consumed in overcoming the resistances of the channel supposed to be straight and of nearly uniform cross-section, and $h_{,,}$ = the part of h consumed in overcoming the resistances of bends and important irregularities of cross-section. In the equation for large rivers, above quoted, $h_{,,}$ is thrown out by the conditions.

The following are the results for the portions of the river indicated in the column to the left. The slope is given in feet per mile. The velocity is stated in miles per hour and in feet per second, and both for a width of 4,000 and 2,500 feet.

		Velocity, width 4000 feet.		Width 2500 feet.	
	Slope.	In m. per hour.	In ft. per second.	In m. per hour.	In ft. per second.
Haverhill to Windsor	3·3	13·07	19·16	12·93	18·97
Windsor to South Vernon	2·5	12·18	17·87	12·06	17·69
South Vernon to Springfield	3·5	13·26	19·45	13·13	19·25
Springfield to Middletown dam	1·25	10·23	15·00	10·12	14·85
Haverhill to Middletown dam	2·7	12·42	18·22	12·30	18·03
South Vernon to Middletown dam	2·5	12·18	17·87	12·06	17·69
Middletown dam to the Sound	7·4	16·02	23·49	15·85	23·25

From the above, the mean velocity for the whole river from Haverhill to Middletown, would have been, assuming that the relations of the land to the sea-level were the same as now, over 12 miles an hour, even supposing the mean width to have been but 2,500 feet.

This great velocity, or even one of 10 miles an hour, is not compatible with the character of the deposits which lie at different levels beneath the surface of the stream—both those at 140 feet below the surface and those at higher levels. The former, away from the region of the mouths of tributaries, consist almost uniformly of nearly incoherent but stratified sand, or sandy loam, and in some parts of clay; and similar fine materials in general constitute the terrace-deposits of the higher terraces (including the terrace-fronts) up to a level within 50 feet of the highest flood level and often nearly to the uppermost plane.*

According to trials, a current of *one-third of a mile* per hour will take up and transport fine earth or clay having the particles ·016 inch in diameter; and one of *two-thirds*, fine sand, the mean diameter about ·064 inch. Accordingly, since the mean diameter of the largest transportable particles varies as

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* Darcy and Bazin, in their *Recherches Hydrauliques*, give the following as the bottom velocity (in feet per second) at which scour commences for the different materials mentioned, and the corresponding calculated mean velocity.

	Bottom velocity.	Mean velocity.
1. Earth	0·26	0·33
2. Loam	0·50	0·65
3. Sand	1·00	1·30
4. Gravel	2·00	2·62
5. Pebbles	3·40	4·46
6. Broken stone	4·00	5·15
7, Chalk	5·00	6·56
8. Hard rock	10·00	13·12

—Cited from the Encyl. Brit., vol. xii (1881), Art. Hydromechanics.

the square of the velocity (supposing them of like density) a stream of 2 miles an hour at bottom would carry along stones of about 0·6 inch in diameter; and one of 4 miles, stones 2⅜ inches in diameter. The mean velocity is generally about a third to a sixth greater than the bottom rate, the differences diminishing as the velocity increases. If the mean velocity were 10 miles an hour, that of the bottom would be over 8 miles (unless greatly impeded by transported material)—rapid enough to scour down to stones and solid rock.

This argument is not based on the depositions made by the stream; for these were more or less made over the flood-grounds of the river as the waters rose; and the waters over flood-grounds, even in the case of rapid streams, are variously impeded by the amount of transported material, friction in the shallow waters, and obstructions, often dam-like, due to the uneven surface beneath; but on the transporting force of the stream at the time of maximum flood, when all the terrace-plains except the very highest were swept by the flowing waters. It may be questioned whether the lower terrace of 60 to 80 feet above present low water, which is almost everywhere—if the mouth of no tributary is near—made of sand or loam where not of clay, was actually the bottom of the flooded stream; whether, the waters did not excavate down to stones and rock, so that this terrace is of subsequent formation. But this supposition does not rid the subject of the fact that the flooded stream did not take up and carry off the sands of its bottom. For the range of higher terraces usually 140 to 160 feet above low water in the river, were at the time under 50 feet in depth of water; and these, away from tributaries, usually consist at top and below of fine sand or loam, or of fine gravel. The great terrace-plain north of White River Junction was one of this kind with 50 feet of water above it; and it consists at surface mostly of fine sand or sandy loam, with some portions of fine gravel; and, below the surface, except near the river, chiefly of sand with some clay. The materials of the corresponding terrace near Windsor are still finer. The high terrace-plain east of Greenfield and south of Turner's Falls, between Montague City and Miller's Falls, called the Montague City plain, lies directly in the way of the Connecticut, as stated on page 191; and although flowed over at the highest flood by water 10 to 30 feet in depth, it consists chiefly of fine sand, or loamy sand, with some clay, except on its eastern and northeastern side, where it received contributions from the violently torrential Miller's River.

Thus all parts of the valley bear like testimony to a velocity in the waters at maximum flood which was not great enough to carry off fine gravel, and this means a velocity not exceeding two miles an hour at bottom; which is the condition in a stream having a mean velocity of 3 to 4 miles.

The transported materials in the waters would have had a retarding effect; but small, since as already shown, they were only sand and finer material, and the fine straticulation indicates a free-flowing stream (p. 93). The deduced mean velocity, over 12 miles an hour, could hardly have been reduced by all the causes of retardation together to less than 9 or 10 miles an hour.

We are thus led to enquire what range of evidence there may be as to the existence of a less pitch in the valley, to cause the less velocity, or as to any other method by which a diminished velocity might have been produced.

One method is by means of *dams;* a second, by *changed relations between the level of the land and sea.*

B. *Dams on the Connecticut Valley as a possible source of less slope in the waters.*—That it may be understood what is to be explained by means of dams, or in other ways, we here review the facts with regard to the clay-deposits and associated sand-deposits of the valley.

It is to be remembered that the sand-beds and those of finer material ordinarily make not only the lower terraces but also the highest, where tributaries are absent, to within 50 and often 20 or 30 feet of their tops; and that this is so even high up the Connecticut, as at Barnet, not two miles south of the junction with the Passumpsic, where these finer deposits extended to a level of 150 to 200 feet above low water in the river.

Clay-deposits are widely distributed about Hartford to a height of 75 feet and less above tide level, or low water in the river. At Springfield, 58 miles in a direct line from the Sound, they are of great extent at a height of 170 feet above the sea level; at Holyoke, 8 miles north, on the west of the Connecticut, and at Willimansett, nearly opposite, on the east side, at 175 feet; on the eastern slope of Mt. Tom, south of Northampton, according to Professor E. Hitchcock, at 178 feet; and over the Amherst region, as I learn from Professor Emmons, of Amherst, at nearly the same level. The dam below Middletown suggests a possible explanation of the origin of quiet water for the making of the clay beds about Hartford; for if the dam were but little more than a third of its final height it would be sufficient; and if raised to within 10 feet of its full height, it might have produced the quiet movement in the waters required for all the clay-beds up to and including those of the Amherst region. That the height of the dam was actually so near its extreme height, when the terrace deposits of Springfield were 50 feet and more below their maximum height, is far from certain. The Springfield, Willimansett and Amherst deposits are situated close by the present river channel, and hence seem to be safe evidence as to the very small velocity of the river, which they might not be if they were more distant flood-ground deposits.

Clay-beds exist just *below* the Middletown dam, on the eastern or Portland side, to a height of 75 feet above modern low water, in a very steep and short valley. The place would seem to be very unfavorable for such fine depositions if the dam were then formed, and especially if at its final height. But it is possible that the ice had made a barrier to the little stream, so that the evidence from these clay-beds is not conclusive against the existence of the dam during their formation.

But, further, extensive clay-beds exist in the high and broad terrace of Montague City, east of Greenfield, 300 feet above tide level. Again, on the terrace-plain, between Windsor and Hartland, 500 feet above the sea-level, or 190 feet above the river, clay comes to the surface in a field so as to be turned up (as I observed) by a plough, the material along the plain elsewhere being fine sandy loam. South of this, in Windsor, the deposits are fine loam and sandy loam to a height of 500 feet, with clay nearly to this height. North of White River Junction clay was exposed near the river at a height of 460 feet above mean tide, or nearly 130 feet above the river at low water. In Hanover, N. H., the clay-beds extend along for 3 or 4 miles or more; and in the village they reach a height of 523 feet above mean tide, or 150 feet above the river—clay having been taken out at this level in excavating for the cellar of Professor Hubbard's house (as he informs me), opposite the northwest corner of the College Square; and on the opposite side of the Connecticut, in Norwich, there are clay beds at corresponding heights up to 500 feet. Just north of the village of Barnet a clay-bed comes to the surface in the terrace-plain near the river at a height of 610 feet above mean tide and 158 above the river. These few examples will no doubt be multiplied greatly by careful exploration.

For making the clay-beds north of Amherst, the Middletown dam would have been of no avail; and besides this dam there is no satisfactory evidence of any other. This is shown by the regularity in the pitch of the terraces along the valley. The valley is comparatively narrow between Mt. Holyoke and Mt. Tom; but the heights of the terraces give no evidence of a dam, and the clay-deposits are at nearly the same high level above and below. Another narrow way for the modern river is between Mt. Toby and Sugar-Loaf, a dozen miles north of Mt. Holyoke; but here the waters of the flooded river had a passage east of Mt. Toby, and a very wide one west of Sugar-Loaf. There are like objections to the location of dams at other places. Mr. Upham says, on this point, especially with reference to the part of the valley north of Massachusetts, that the idea of dams along the valley is not sustained by the topography of the valley or the distribution of its terraces.

As dams have, therefore, not existed where they would have been needed to reduce the slope of the stream and make a velocity that would admit of extensive depositions of sand through all the valley and of clay-beds in many parts to various heights up to 610 feet above the sea-level, we may consider what effect may have come from changed conditions in the level of the land and sea.

C. *Slope and velocity under changed relations in the level of the land and sea.*

a. *Evidence of a change afforded by the heights of Elevated Sea-beaches.*—The fact of a wide difference between the flood era and modern time along the coast region is put beyond question by the heights above existing tide-level of shell-bearing beach-deposits.

The facts are well known. The more important are here tabulated:*

	Latitude.	Height.
New Haven or New London, on the Sound,	41° 14′	15 to 25
Sankaty Head, Nantucket,	41° 17′	45
Point Shirley, near Boston,	42° 19′	75 to 100
Lewiston, Maine,	44° 6′	200
Mt. Desert, Maine,	44° 20′	217
Colchester, Vt., (4 m. N. of Burlington, on L. Champlain),	44° 33′	335
Middlebury, Vt.,	44° 10′	403
Montreal,	45° 31′	520
Les Éboulements, on St. Lawrence River,	47° 30′	about 600
Murray Bay, on St. Lawrence River,	47° 45′	

The facts prove (1) a difference of level compared with tide-level between the era of the beach-deposits and the present; and (2) an increasing amount of difference northward. They are all from the coast it is true, but from the coast of the northwest side of New England as well as from its eastern, southeastern and southern borders; and in view of their wide geographical range, and especially the fact, already made manifest, that the valley of the Connecticut must have had diminished pitch during the era of the flooded river, we may believe that the interior of New England experienced the changed rethe sea-level that we find indicated along the sea- [illegible]

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* The heights at Éboulements and Murray Bay, on the St. Lawrence, I have received from Dr. J. W. Dawson, of Montreal. The beds at Middlebury, Vermont, are of clay without marine shells; but, according to Professor C. H. Hitchcock, there is no higher land between them and Lake Champlain, and they could not have been made unless the waters of the lake were at the same level. The heights on Long Island Sound (north side) are based on stratified deposits along or near the Sound, but not shell-bearing. The shells in the Mt. Desert deposits indicate a considerable depth of water.

[illegible] At Montreal and Lake Cham- [illegible] Murray Bay [illegible] New Haven [illegible] New London [illegible] of Long Island Sound.

[illegible]

	Distance	Rise	
[illegible]	[illegible]	[illegible]	[illegible] feet per mile.
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	

[illegible]

[illegible]	[illegible]	[illegible]	[illegible] feet per mile.
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	

[illegible]

[illegible]	[illegible]	[illegible]	[illegible] feet per mile.
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	

[illegible]

[illegible]

[illegible]

We thence have 1·25 feet per mile (=50 seconds nearly in angle) as the mean rate of change northward along the Connecticut valley.

The line D S on the section (figure 2, Plate 2) represents the mean-tide level thus deduced. It is drawn from a point on the Sound marking 25 feet above mean-tide level (supposing the change on the Sound to be 25 feet, though along by the mouth of the Connecticut it may not have exceeded 15 feet), and rises in the direction of the valley northward, at the rate of 1·25 feet per mile.

It cannot be assumed that the rate was equable throughout the valley. It may have been less than the deduced rate to the south, and greater northward; and this is shown beyond to have been probably a fact. If the rate had been one foot per mile for the first third of the length of the valley, or to Springfield, and 1·33 feet for the rest of the way to Haverhill, the height at Haverhill would have been very nearly the same as above deduced, or 268 feet.

b. Effects of the change while the river was low.—If the river were, for a while, at or near modern low-water level (and it probably was so), the change of 1·25 foot a mile, would have taken out all the mean slope from the several parts of the valley, excepting the abrupt descents at the falls. The tides would have extended beyond the Holyoke dam, eight miles above Springfield, obliterating the falls and have stood 15 feet above its top; and have reduced Turner's Falls nearly 30 feet in height. The elevation of low-water level above the sea would have been only 35 feet at South Vernon, or the Massachusetts boundary; at Windsor, 83 feet; at Haverhill, 120 feet. Hence the descent between South Vernon and Windsor would have been only 48 feet, which is three feet less than the fall (51 feet) at Bellows Falls, situated between these two points; and the descent between Windsor and Haverhill would have been only 37 feet, which is three feet less than the fall (40 feet) at the falls between Hanover and White River. Since these falls would have wasted, by friction at bottom, any velocity which might have been gained by descent, the Connecticut River would have been for the most part a series of nearly still-water stretches with falls at a few distant points. This condition would have continued, with but little change as to the effect of the dams, after the waters had risen 20 to 25 feet above low water, as in a modern flood.

One possible consequence from such a state of things would have been an opportunity for clay and fine-sand depositions, without the need of help from dams; and another, an almost complete absence of the work of erosion—since the waters would have had but slight working force, anti the present low-water level would have been the lowest possible level at which this little work could have been done. An earlier consequence might have been—the deposition of the till with no more stratification where it fell into the waters than when dropped outside of them.

c. Effects of the change after the flood had made progress.—When the river had risen to a height of 60 or 80 feet above low-water level, the falls in the course of the valley would no longer have been mere nullities as regards their effect on the mean velocity of the stream immediately below them; for the velocity acquired by the descent would have been only in part wasted by friction at bottom.

But when, beyond this, maximum flood level had been reached, so that the surface of the water was 200 feet and more above low-water level, the falls would have lost all influence on the velocity by their submergence, and the general slope of the flood would have conformed nearly to the general pitch and width of the valley. As the upper deposits were made by the stream when near and at this maximum level, and the lower were, at the same time, beneath the sweeping flood, it becomes of the highest importance to compare, as nearly as possible, the mean velocity at the time with the amount of transporting power indicated by the nature and condition of the stratified deposits.

If the rate of change along the valley with reference to the ocean level were, as above deduced, 1·25 feet per mile (and the change at the Sound 25 feet,) the height of the water-surface above mean tide would have been at—

Haverhill	383 feet.
Windsor	299 "
South Vernon,	236 "
Springfield,	135 "
The Middletown dam	137 "

The mean slope and velocity on the above supposition, would ence have been for the part from—

	Distance in miles.	Slope ft. per m.	Velocity, with width 4000 ft.		Velocity, with width 2500 ft.	
			m. per h.	ft. per sec.	m. per h.	ft. per sec.
Haverhill to Windsor	41	2	11·515	16·89	11·39	16·70
Windsor to South Vernon	49	1·3	10·33	15·15	10·22	15·00
. Vernon to Springfield	44	2·3	11·93	17·50	11·81	17·32
pringfield to Middletown	38	0	----	----	----	----
Haverhill to Springfield	134	1·9	11·37	16·67	11·25	16·50
Middletown dam to Sound	26	5·2	14·65	21·49	14·51	21·28

According to the above, the river at maximum flood would have had no slope between Springfield and Middletown, and have therefore been in this part a great lake. But this condition is shown to be improbable by the coarse character of the deposits in the Springfield region that were made at maximum flood: and this is one of the reasons referred to on page 198. for believing that the slope in the lower third of the valley was reduced to a less rate than 1·25 feet per mile. Taking it at 1 foot per mile to Springfield, as there suggested, and 1·33 feet above Springfield, it gives for the height of the water-surface above mean tide at

Haverhill	387 feet.
Windsor	307 "
South Vernon	248 "
Springfield	151 "
The Middletown dam	144 "

Excepting south of Springfield, the changes in slope thus introduced between the places mentioned are small—that from South Vernon to Springfield becoming ·2·2: from Windsor to South Vernon 1·2: that from Haverhill to Springfield, 1·8: and that from Haverhill to Windsor continuing at 2: so that the velocities would be but slightly altered. Between Springfield and Middletown the pitch becomes about 3 inches a mile.

According to the preceding table, the velocity from Haverhill to Springfield, notwithstanding this change of one-third in the slope of the stream. would still, when at the highest flood-level, have exceeded 10 miles an hour for a mean width of 2500 feet, the pitch to Springfield being nearly 2 feet a mile.* And if we assume that bends and other obstructions, and transportation would have reduced the mean velocity 20 per cent, it would still be 8 miles an hour, with a bottom velocity over 6, and therefore much in excess of that indicated by the character of the bottom deposits.

It is quite certain that the slope must have been much less than that which corresponds to a height of water-surface at Haverhill of 387 feet, or a pitch in the valley to Springfield of 21 inches a mile. But it is not so evident what slope would harmonize the facts; that is, would cause a velocity sufficient to make or leave coarse valley deposits near and at flood level, such as might be made by a current of 4 to 6 miles an hour, and, at the same time, leave almost undisturbed beds of sand or of fine pebbles along its bottom, whether at depths of 50 or 150 feet, this alike for the stream north of South Vernon and south of it, and even for the part north of Wells River to Barnet as well as south of Wells River.

By calculation, using the same elements as before, taking the width at 2500 feet and making no allowance for obstructions by bends or transportation, it appears that a slope in the water surface of only 0·383 inches a mile would give a mean velocity of 4 miles an hour; and one of 0·923 inches, a mean velocity of 5 miles. The Mississippi along a straight portion at Carrollton, during high water, when the *maximum* depth was 136 feet and the slope but 1·3 inches, has a mean velocity of 4 miles per hour. (See beyond.)

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* According to the formula, the velocity varies approximately as the 4th root of the slope, and, consequently, to diminish the velocity from any rate to one-half, the slope must be reduced about a sixteenth.

Making allowance for the probable amount of resistance from the sources above mentioned, it would seem that a slope of 2 inches a mile to Springfield would have been sufficient to meet the conditions; and that one of 3 inches would have been too great. But suppose it 3 inches a mile; a change in the pitch of the valley amounting to 18 inches a mile would have been needed to produce it. If we suppose it 6 inches—which is a very large pitch in any stream under continuous flow (that is, not broken into parts by dams) which was the fact with the flooded Connecticut down to Middletown—the needed diminution in the pitch of the valley would have been 15 inches a mile. This amount, 15 inches, added to the 15 inches a mile deduced from the elevated sea-beaches, would make for the total diminution in mean rate of pitch to Springfield 2½ feet a mile; and if the amount were 18 inches, the total would be 2¾ feet a mile, which would make the change at Haverhill hardly 50 feet less than at Montreal.

The later change, whatever its amount, would have been a continuation of the former. Whether it was confined or not to the Connecticut valley—a line of weakness in former geological eras—must be determined by the study of other valleys to the east and west, especially the Merrimack on one side and that of Lake Champlain and the Hudson on the other. It is a strange fact that the terrace formation of the southern part of the Lake Champlain region, and of its continuation along Lake George to Albany on the Hudson has not yet been carefully studied.

In view of so great changes in the slope, reining in the waters, the floods of the Connecticut Valley lose something of the magnificence portrayed in the high terraces. But, on the other hand, the conditions are brought within more reasonable, or less improbable, limits.

It is interesting and instructive to compare, in this connection, the velocity and other elements of a straight portion of the Mississippi River at high water. According to the measurements of such a portion of the river in the vicinity of Carrollton,* referred to above, made by the Delta Survey in 1851 under the special charge of Professor C. G. Forshey, and published on page 316 of the report of Humphreys and Abbot as one of the thirty cases upon which data their formula for velocity was based, the elements were as follows:

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* Carrollton is 121 miles from the mouth of the Mississippi, and at high water the surface of the river is 15·2 feet above sea-level.

Area of cross-section in square feet.	Width in feet.	Wetted perimeter in feet.	Maximum depth in feet.	Mean velocity per second.	Slope.
193,968	2653	2693	136	5·9288	0·00002051

The *calculated* velocity found by the formula was 5·9673 per second, giving a difference of 0·0385 feet. The velocity obtained is almost exactly four miles an hour; and the slope to which this velocity corresponds is, as already stated, 1·3 inches per mile.

By means of the formula, we have, from the same conditions in the Mississippi as to dimensions, but with other assumed slopes, the following results:

Slope per mile in feet.	Slope per foot.	Velocity in miles per hour.	Velocity in feet per second.
1·75	0·0003314	8·129	11·918
3·0	0·0005682	9·32	13·670
4·5	0·0008523	10·32	15·145
6·0	0·0011364	12·47	18·292

The case of the Mississippi differs from that of the flooded Connecticut in the less average depth—the *maximum* being 136 feet. The Mississippi River was more like the New England stream when it was itself flooded from the same cause; when its lœss deposits were formed, according to Professor E. W. Hilgard, not many miles above the head of the delta, to a height of 450 feet above the sea. Its average width below the mouth of the Ohio exceeded 50 miles. Professor Hilgard points out the fact* that the "Grand Gulf Group," of the border of the Gulf of Mexico, along, and east and west of, Louisiana, (representing the Tertiary after the Eocene,) is capped near the gulf by beds of stratified drift to a height of 500 feet above the gulf; and that the facts indicate that an elevation of the gulf border, and of that portion of the Mississippi valley, was begun in the early Tertiary and went on until it had reached a height in the Glacial era of 900 feet, after which there was a reverse movement. In that reverse movement (or after it and a new bend upward), the region must have been long at or near 450 above the sea (if there was not, in place of part of it, a diminution of pitch northward), in order that the slope of the water-surface of the river should have been reduced to a minimum, so as to allow of such fine deposits as the lœss.

On this view, the Mississippi had a dam, and was put thereby into a lacustrine condition, right for making lœss or loamy deposits. The Connecticut had a dam also; but it continued nevertheless to be a river throughout, its loamy deposits and clay-beds being subordinate in the upper terraces to its sand-beds and those of coarser constitution.

* In this Journal, xxii, 58, 1881.

[To be continued.]

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXIII, MAY, 1882.]

ART. XXXVIII.—*On the Flood of the Connecticut River Valley from the Quarternary Glacier*; by J. D. DANA.

[Continued from page 202.]

THE facts, presented in the preceding part of this paper, on the dimensions and velocity of the flooded Connecticut appear to make it certain that, during the era of the great flood, the pitch of the Connecticut valley was very much less than it is now, and that a change equivalent to 1 foot a mile from the Sound to Springfield, and 2½ feet a mile to Haverhill (and an undetermined distance beyond)—but corresponding to some curving plane between the extreme points—would not be too great to meet the requirements.*

But I have not said that the land over the interior of New England was depressed to the amount stated, or to any amount. It has been left an open question whether the change was a change in the sea-level or in the land-level.

Leaving this point for discussion in another number of this Journal, I here take up the subject of the disappearance of the ice from the Connecticut valley.

5. *The Retreat of the Glacier.*

The *rate* of retreat or disappearance of the ice along the Connecticut valley and from the Connecticut River drainage-area had a relation to the amount of discharge of the flooded river; and the time required for the retreat a like relation to the amount of ice to melt. But there are various unknown quantities connected with this subject, and only some very general conclusions can be looked for.

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* This curving plane would make right the heights for Middletown and Springfield on page 199, where the former is, by the assumed rate of pitch, the higher.

(1.) *Drainage-area.*—The present drainage-area of the Connecticut, north of Massachusetts, covers about 8,500 square miles; between the northern Massachusetts line and Hartford, 2,100 square miles; and between Hartford and the Sound, 450 square miles; making in all 11,050 square miles. The Hartford limit is here made to extend south of Hartford on the west, so as to include the whole drainage-surface of the Farmington River, which joins the Connecticut north of Hartford. The area covered by the Quinnipiac River might also be added, since the overflows from the Connecticut River valley, at Northampton and south of this point, so far as they emptied into the Sound by a separate outlet, reached it by the Quinnipiac valley. But the area is not over 50 square miles.

(2.) *Amount of ice over the drainage-area.*—The mean thickness of the ice in and west of the White Mountain region, judging from the glacial scratches on the White Mountains, and on Mt. Mansfield of the Green Mountains, was probably about 5,000 feet; at the sources of the Connecticut River, 75 miles north, on the borders of Canada, at least 6,000 feet; and to the south near the Massachusetts border, not far from 3,500 feet. The mean thickness for the whole area, 8,500 square miles in extent, thence deduced, is about 4,500 feet; and, if so, the whole amount of ice covering the drainage-area north of Massachusetts, at any one time before melting had made much progress, would have been about 7,250 cubic miles.

Over the more southern part of the drainage-area, 2,550 square miles in extent, the mean thickness was probably near 2,000 feet. In this the thickness along the north shore of Long Island Sound is taken at 1,000 feet; and it is put at this figure rather than lower because the glacier continued flowing southward and eastward for at least 34 miles, it having extended across the Sound, and landed large bowlders, some of more than a hundred tons weight, with a large amount of moraine material (referred to the terminal moraine) on the south side and other parts of Long Island; and the chief part of the fall necessary for motion came from a northward increase in the thickness of the ice, the Sound being a shallow trough 20 miles or so wide. A slope of 0° 25′ would give a pitch of 38·39 feet per mile (= 1 : 137·5), and make the thickness along a line 34 miles north-northwest from the south side of Long Island, 1305 feet; and one of only 0° 20′ would give a pitch of 30·72 feet per mile (= 1 : 171·8), and a thickness of 1,044·5 feet.[*] On the above assumption the amount of ice in this part of the drainage-area at any given time would have been 965 cubic miles, making the total about 8,215 cubic miles.

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[*] In Greenland a thickness of more than 900 feet exists according to Helland, at the very end of the Jakobshavn glacier, this being proved by the thickness of the icebergs broken from it.

(3.) *Sources of the Water.* — Melted ice and unfrozen waters from the precipitation over the drainage-area were the sources supplying the flooded streams.

The precipitation, to produce the snows needed for the Glacial era, must have been large, much larger than now. The amount at the present time for the part of the drainage-area north of Massachusetts averages 42 inches a year, and for the part south, 46 inches; while on Mt. Washington, just east of the area, the annual fall is between 55 and 80 inches. In 1873, 78·56 inches were registered on Mt. Washington.

In the Glacial era the conditions must have occasioned still more abundant precipitation. The ocean was, in all probability, much warmer than now, either through the shallowing of the Arctic seas, which shallowing would have diminished much the southward currents of cold polar water, and also the extreme northward flow of the Gulf Stream; or in some other way. In addition, the border region of the continent, in these and higher latitudes, had not merely snow-clad heights, but ice-made heights, from the sea-margin to the top of the lofty ice-range. Moreover, the region of New England was within the more seaward portion of the icy slopes.

The relations were consequently like those between the tropical Indian Ocean and the seaward mountain ridges of India, though less extreme. In India, at many localities, the mean, annual rain-fall is 100 to 160 inches, while at three stations on the Ghats, in Bombay, it is over 250 inches, and at one in Assam, nearly 500 inches. In such facts we have seemingly sufficient reason for estimating the average annual rain-fall of the Connecticut valley during the Glacial era to have been at least as high as 120 inches. The present high average on the isolated White Mountains is good evidence that 90 inches would be too small an estimate, and the more so since during the four months in which half of the precipitation there takes place, June, July, August and September, the slopes are, with small exceptions, free from snow—Mr. Schott's tables (page 56) making the mean for the four years of observations 67·12 inches, and for the four months just mentioned, 33·83 inches.

The facts make it apparent, whether the above estimate be precisely right or not, that the amount of precipitation was far greater than in any modern glacial region. And the same must have been true for the southern portion of the ice-slope, *west* of New England, over which would have blown moisture-ladened winds from the region of the great Mediterranean sea of the continent; though possibly, owing to the distance from that sea and the position of the Appalachians, the annual precipitation north of the Ohio may have been increased somewhat less than over New England.

From the condition of Greenland,*—a semi-continent, covered by a continuous glacier-mass more than a thousand miles long

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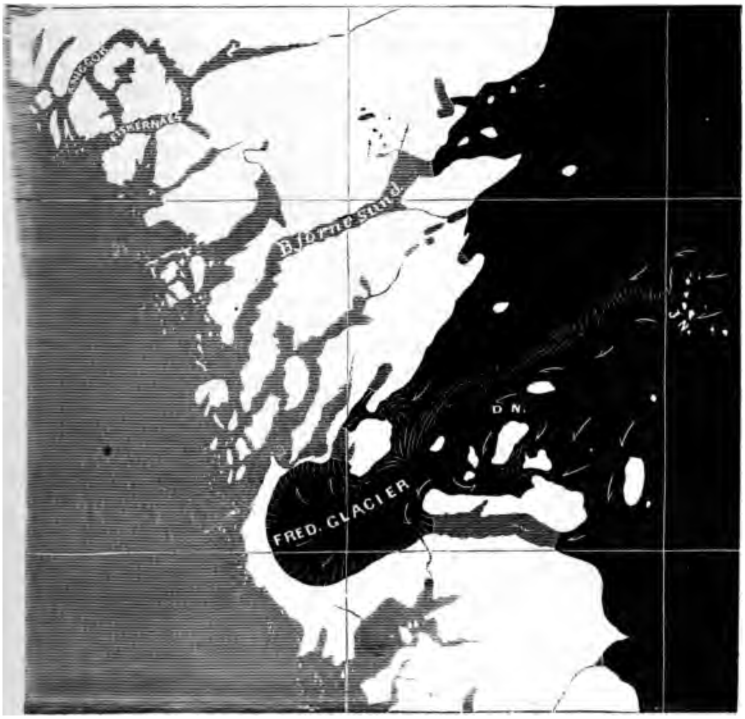
* The chief sources of information with regard to the interior of Greenland are: (1) the exploration, in July, 1870, of Nordenskiöld over the ice for 28 miles, sixty miles south of Jakobshavn, near the parallel of 68° 20′, (*Geol. Mag.* for 1872); and (2) that of Lieutenant J. A. D. Jensen, in 1878, with Mr. A. Kornerup as geologist, who started on the Frederikshaab glacier, between the parallels of 62° and 63°, and traveled 47¼ miles in an E.N.E. direction (*Meddelelser om Grönland*, Copenhagen, 1879, Part first).

1.



The black part, ice; white, land; shaded, water; J. N., Jensen's Nunataks; D. N., Dalager's Nunataks; white lines on the black, crevasses; arrows, glacier-flow.

Nordenskiöld saw an undulating surface of ice, white and moraineless, much intersected by crevasses, and furrowed by innumerable rivers, and one "copious, deep and broad river between banks of blue ice," whose banks he followed until he saw "the whole immense mass of water rush down a perpendicular crevasse into the depths below." There was dust over portions of the surface, and with it, as detected by his companion, Mr. Berggren, great quantities of a minute alga, in the form of threads of usually 4 or 8 cells, along with some *Protococcus nivalis*, and, in one place, so much of the material lay together, (collected by streams then dried up), that it had become putrescent in the sun, "so as to emit a most unpleasant odor, like that of butyric acid." Nordenskiöld says that the algæ tend to make rapid melting of the ice under the summer's sun. The height reached by Nordenskiöld and several hundred wide, and leaving outside only a fringe of fiords and islands generally but 30 to 60 miles in width,—we may derive many facts illustrating this subject. We learn from it that a continental glacier (1) would have crevasses of indefinite number and extent, either transverse to the direction of motion, longitudinal, or radial, according to the bottom over which it moved and the attendant conditions; that (2) it would be covered extensively, in the warmer season at least, with fresh-

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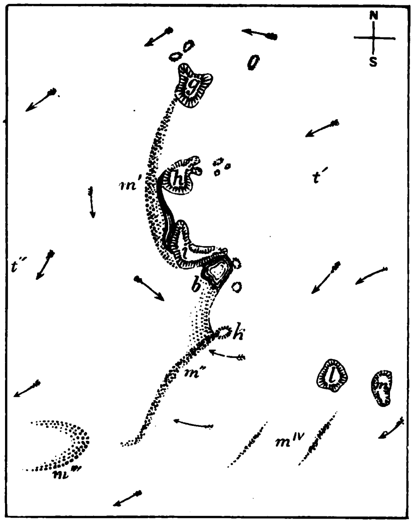
was 2,200 feet, and the mean slope of the ice-surface on the way, as deduced from the height, was 0° 26′, equivalent to 40 feet per mile (1: 132).

Lieut. Jensen, at the limit of his inland ice journey of 47½ miles from the foot of the Frederikshaab glacier, reached a cluster of rocky peaks, rising from beneath the glacier—*Nunataks* of the Greenlanders (J. N., fig. 1). The heights above the sea of the four largest were severally, commencing to the north, 5,623 (*g*), 5,184 (*i*), 5,654 (*k*), and 5,580 (*m*), feet. (See fig. 2 below.) From these peaks, which stand like islands in the sea of ice, moraines of stones and earth (some of the stones 20 feet in their dimensions) extend for 1 to 2½ miles, (*m′*, *m″*, *m‴*, *m⁗*, fig. 2) and dust, by the aid of the storm winds, is drifted off for wide distribution over the glacier. The moraines, after a short outside existence, disappeared beneath the ice, the stones dropping down the crevasses that were from time to time opening (the account says) as the glacier moved on. The varying direction of the moraines, and the eddies in the flowing ice, due to the obstructing ridge (of which the Nunataks are the peaks), which these directions indicate, are remarkably instructive. The arrows show the inferred direction of movement. The moraine *m′*, 2½ miles long, is made mostly of polished stones, which appear therefore to have traveled far, and not to be the debris of the nunataks. The *m″* and *m‴* have no connection with any visible nunatak. At *b* is a lake 824 feet in diameter, and toward it the ice around slopes from a height of 4,900 feet to that of 4,120 on its borders. The glacier had a height at *t*, east of the nunataks, of 5,150 feet. The slope of the ice-surface for the distance traversed averaged 0° 49′, or about 75 feet per mile (1 : 70); and it was evident that the movement of the glacier depended on this slope. Crevasses were numerous along the route transverse to the line of movement as well as longitudinal and radial (see fine lines along the route on fig. 1); and fresh-water streams were common, and water-falls also.

2.



The largest of Jensen's nunataks consisted mostly of hornblende schist in bold flexures, with mica schist and gneiss. Twenty-seven species of plants were collected from them by Mr. Kornerup, and among these were the grasses *Luzula hyperborea* and *Carex nardina*, widely spread, *Trisetum subspicatum* and *Poa trichopoda* in scattered tufts; the sorrel, *Oxyria digyna*; the white-flowering *Cerastium alpinum* and *Saxifraga oppositifolia*; the little blue-flowering *Campanula uniflora*; *Potentilla nivea*, *Ranunculus pygmæus*, *Silene acaulis*, *Cassiope hypnoides*, *Armeria Sibirica*; and the yellow-flowering poppy, *Papaver nudicaule*, which was taken water streams, ending their short career by a leap down the crevasses; and that such streams might often attain large size before making their plunge to sub-glacial depths; that (3) the melting at surface and thereby the wasting of the ice would probably have been promoted by a wide distribution of microscopic algæ; that (4) sub-glacial streams would have been numerous and large, and that they might have kept up their flow even through the coldest season; that (5) sub-glacial streams, flowing out from beneath the discharging glacier, would have transported fine earth and clay, the results of glacier abrasion,

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and several hundred wide, and leaving outside only a fringe of fiords and islands generally but 30 to 60 miles in width,—we may derive many facts illustrating this subject. We learn from it that a continental glacier (1) would have crevasses of indefinite number and extent, either transverse to the direction of motion, longitudinal, or radial, according to the bottom over which it moved and the attendant conditions; that (2) it would be covered extensively, in the warmer season at least, with fresh-

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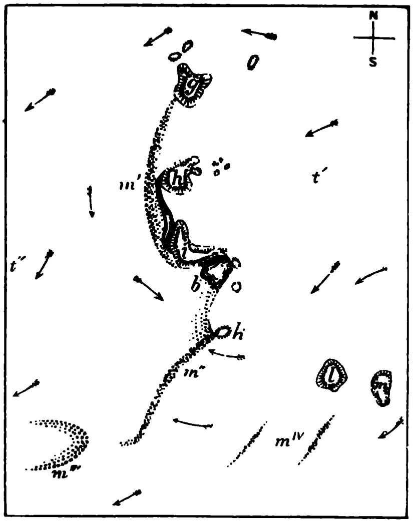
was 2,200 feet, and the mean slope of the ice-surface on the way, as deduced from the height, was 0° 26′, equivalent to 40 feet per mile (1 : 132).

Lieut. Jensen, at the limit of his inland ice journey of 47¼ miles from the foot of the Frederikshaab glacier, reached a cluster of rocky peaks, rising from beneath the glacier—*Nunataks* of the Greenlanders (J. N., fig. 1). The heights above the sea of the four largest were severally, commencing to the north, 5,623 (*g*), 5,184 (*i*), 5,654 (*k*), and 5,580 (*m*), feet. (See fig. 2 below.) From these peaks, which stand like islands in the sea of ice, moraines of stones and earth (some of the stones 20 feet in their dimensions) extend for 1 to 2½ miles, (*m′*, *m″*, *m‴*, *m″″*, fig. 2) and dust, by the aid of the storm winds, is drifted off for wide distribution over the glacier. The moraines, after a short outside existence, disappeared beneath the ice, the stones dropping down the crevasses that were from time to time opening (the account says) as the glacier moved on. The varying direction of the moraines, and the eddies in the flowing ice, due to the obstructing ridge (of which the Nunataks are the peaks), which these directions indicate, are remarkably instructive. The arrows show the inferred direction of movement. The moraine *m′*, 2½ miles long, is made mostly of polished stones, which appear therefore to have traveled far, and not to be the debris of the nunataks. The *m″* and *m‴* have no connection with any visible nunatak. At *b* is a lake 824 feet in diameter, and toward it the ice around slopes from a height of 4,900 feet to that of 4,120 on its borders. The glacier had a height at *t*, east of the nunataks, of 5,150 feet. The slope of the ice-surface for the distance traversed averaged 0° 49′, or about 75 feet per mile (1 : 70); and it was evident that the movement of the glacier depended on this slope. Crevasses were numerous along the route transverse to the line of movement as well as longitudinal and radial (see fine lines along the route on fig. 1); and fresh-water streams were common, and water-falls also.

2.



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to make aqueous deposits, which might or might not be free from stones or bowlders.

Dr. Rink, the Greenland explorer, and for many years, Government Inspector of South Greenland, states, in his "Danish Greenland," (1877) that the sub-glacial streams which flow out from beneath the ice in the ice-discharging fiords, are very copious and sometimes violent torrents, making whirlpools a hundred feet in diameter as the waters escape from sub-glacial confinement; that they probably branch widely over the country like a regular river system; and he refers to the authority of the natives, as well as to the observations of explorers. He observes that, according to his estimate,* out of the 10 inches of annual precipitation—the mean amount—only 25 per cent, or 2½ inches, are needed to supply the loss of ice from the discharge of icebergs; and that the rest, apart from what is lost by evaporation, makes up the amount of loss from melting, indicated by the sub-glacial waters. An annual supply to this end of only 6 or 7 inches could not produce the largest of rivers.†

From these facts we may hence assume that the great glacier of Eastern North America would have had

(1) Crevasses, with only local exceptions;

(2) Surface streams flowing with nearly pure waters over nearly pure ice, suddenly becoming sub-glacial by descending the crevasses; and

(3) Sub-glacial streams as much more extensive than those of Greenland as the precipitation was more copious and the drainage-areas larger.

If in Greenland 60 or 70 per cent of the precipitation is a measure of the amount of water contributed to the sub-glacial streams, 60 per cent. may have well been the amount in New England during the progress of the Glacial era; and this, with an annual fall of 120 inches, would have been 72 inches or 60 inches with one of 100 inches. This estimate can hardly be over-large considering that tropical and warm-temperate regions were not far distant, and that the summers, if it were a fact that they were shorter than now, were proportionally hotter. When the glacier began its decline, the proportion of the precipitation becoming sub-glacial would have gradually increased, and so on to the end. And, consequently, as the amelioration of the climate made progress, the melting would have augmented in rate through the increasing warmth of the winds. The fact that glacial conditions tend to perpetuate themselves is well illustrated in the present state of Greenland. But in North America, situated on the wind-receiving side of a warm-temperate and tropical ocean, whose tropical waters lay against its southern border for more than a thousand miles, the strength of the tendency would have been severely tested.

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* Based chiefly on the flow of ice in the Jakobshavn fiord, as measured by Helland.

† According to Helland, the mean precipitation at Jakobshavn for the year between July 1873 and July 1874, was only 8¼ inches, and for the year following, 7 inches.

Pressure and friction would have been other sources of melting; and perhaps, in view of the breadth of the area covered by the glacier, some small amount may have been occasioned by subterranean heat.

(4.) *Mean annual discharge of the Connecticut River at the time of maximum flood.*—The data for calculating the amount of discharge of the flooded river are: (1) the estimated mean width of the river, 2,500 feet, (the reduced estimate); (2) the mean depth, 140 feet; and (3) the mean velocity, which we may take at 3 and 4 miles an hour. The length of the river from Wells River to the Sound is 200 miles. Hence, 66⅔ hours for 3 miles an hour, and 50 for 4 miles, would have been required, to pass into the Sound the waters, that at any one time occupied the channel.

The estimate of 140 feet for the depth can hardly be too great, seeing that the highest terraces are, at the south, 200 feet high above modern low-water; and to the northward, 200 to 265 feet. The view that the range of upper terraces, including the so-called delta-terraces, mark approximately the high-water level, is the common one with all that believe the terraces to be of fluvial origin; and I feel under obligation to add, inasmuch as the different idea about the "normal highest terraces" and the "delta terraces" of the Connecticut, opposed in the earlier part of this paper, is from one of the New Hampshire Geological Reports, that this accepted view is that sustained and taught by Professor C. H. Hitchcock, the head of the New Hampshire Survey.

The amount of water lying in the channel at any one moment would have been 2·511 cubic miles; and the daily discharge, if the velocity were 3 miles an hour, nearly 0·9 (0·904) cubic miles; or if 4 miles an hour, nearly 1·2 cubic miles (1·205). At the two rates of flow mentioned, the amount of water discharged during a year would have been about 330 and 440 cubic miles.

(5.) *Annual loss of ice from the melting.*—Now comes the question how much of this water came from the melting glacier-ice, and how much from the cotemporaneous precipitation; or how much did the amount of water exceed the amount of precipitation?

If all of the water came from the ice, the amount of ice melted—taking its specific gravity at 0·92—would have been, at the two rates of flow in the river, about 359 and 478·5 cubic miles.*

The amount from the precipitation to be deducted does not diminish greatly these numbers, even if all of it went to increase the floods. With a mean annual rain-fall of 120 inches, or 10 feet, this amount for the part of the entire drainage-area north of Massachusetts, would be only 16·1 cubic miles; and for the whole drainage-area to the Sound, 21·8 cubic miles.

This amount, 21·8 cubic miles, is too large by the amount which would have been lost through evaporation, soil-absorption, chemical changes in and beneath the glacier making oxides and hydrates, and in other ways. An estimate of these losses may be derived from the modern Connecticut.

The annual discharge of the Connecticut, as determined by measurements made under the direction of General G. K. Warren, of the U. S. Engineer Corps, by General T. G. Ellis,† at Hartford, Ct., where low water in the stream is almost exactly mean-tide level, it being only ·045 feet below it, was as follows for the years mentioned:

Year.	Discharge in cubic feet.	Year.	Discharge in cubic feet.
1872	638,070,000,000	1875	570,649,000,000
1873	727.160,000,000	1876	706,291,000,000
1874	733,103,000,000	1877	526,261,000,000

The largest of these sums, that for 1874, corresponds nearly to 5 cubic miles (more exactly 4·98).

The amount of annual precipitation over the drainage-area *north of Hartford* to the sources of the Connecticut (allowing 42 inches as the mean for the part north of Massachusetts and 46 inches for the rest north of Hartford), averages nearly 7·17 cubic miles. Consequently the amount discharged at Hartford in 1874, was 69·5 per cent of the precipitation; so that the loss in all other ways was little over 30 per cent. In 1877, a year of minimum discharge, the amount was 50 per cent.

The proportion of 70 per cent more correctly represents the condition in the era of the glacier-melting than that of 50; for it is the proportion during a year of great Connecticut floods; and these floods are dependent, in nearly all cases, (1) on the large amount of snow and ice of the winter or spring season, and to a considerable extent (2) on the frozen state of the ground over the hill slopes and much of the country, favoring an easy slipping of the waters over the surface without absorption by the soil,—conditions eminently characteristic of the era of the

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* The specific gravity is here taken too high because of crevasses and want of compactness of glacier-ice; but this error, for the calculation of which no specific data exists, is not here of importance. Helland found the specific gravity of the ice of a large iceberg only 0·886, this low rate being due to linear air bubbles which thoroughly permeated it.

† Annual Report of the Chief of Engineers for 1878. Appendix B 14.

Glacial flood. This point is further exhibited in the following table, in which the monthly discharge of the Connecticut at Hartford, for the years 1872 to 1877, is given from General Ellis's Reports; and also the rainfall (snow included) for the same years at Lunenburg, Vermont, two miles west of the Connecticut, in lat. 44° 28′ N., long. 71° 44′ W., at a height of 1124 feet above the sea; Hanover, New Hampshire,—on the east bank of the river, in lat. 43° 42′ N., long. 72° 17′ W., at a height of 530 feet above the sea; and at Amherst, Massachusetts, in lat. 42° 22′ N., long. 72° 34′ W., at a height of 267 feet above the sea; the first, from tables kept by Dr. H. Cutting of Lunenburg; the second, from the Dartmouth Observatory at Hanover (received from Prof. R. Fletcher); and the third, from the tables of Prof. E. S. Snell. The table shows that the floods are not the immediate effect of great rains, and this is plain from mere inspection.* So in the Glacial era, the loss of water by soil-absorption was at its minimum, by growing vegetation almost null, and by chemical processes of oxidation and hydration† very small, while ice to melt and melting and frozen ground to flow over were essentially indefinite in extent.

An allowance, therefore, for the loss from evaporation and other causes, of 20 to 25 per cent, during the glacier-melting, cannot be far from right. Taking the mean of these numbers, 22½ per cent, the amount for the whole precipitation, 21·8 cubic miles, becomes 16·9 cubic miles as the part contributed to the discharge of the flooded river; and this in the state of ice is 18·4 cubic miles. Consequently all the discharge but this portion would have been derived from the wasting glacier—which makes the waste per year (p. 367) 460·1 cubic miles if the velocity of the river were four miles an hour, and 340·6, if three miles, the former equivalent to about 1·26 cubic miles per day, and the latter to 0·933.

(6.) *Disappearance of the Ice.*—If the loss of ice by melting were 460·1 cubic miles per year, and this amount continued to be the loss uninterruptedly, 8,215 cubic miles of ice would have been carried off in about 18 years; and if the annual

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* One marked exception occurred in August, 1856, when the waters of the river reached a height of 23·33 feet at Hartford, or but 25 per cent short of the highest on record (that of May, 1854, when the height was 29·83 feet). But the precipitation at that time was enormous, having been in that August 12·132 inches at Amherst (Snell), and 11·68 inches at Wallingford, Connecticut (B. F. Harrison, in this Journ., xxi, 497, 1881).

† The loss by hydration here alluded to is in part that used in making the clay of the glacier discharge which is abundant in Greenland as well as in the products—bowlder-clay—of the Glacial era. Such clay has been made by the decomposition of the feldspar which the glacier-movements grind up, and when pure contains 13 per cent or so of water. The decomposition is a remarkable fact; but it is possible that the decomposition of the algæ of the glacier may have made carbonic acid to promote it.

	Discharge in millions of cubic feet.	Monthly precipitation.				Discharge in millions of cubic feet.	Monthly precipitation.		
		Lunenburg.	Hanover.	Amherst.			Lunenburg.	Hanover.	Amherst.
1872.					1873.				
Jan.	29,288	1·95	2·88	1·51	Jan.	64,430	3·85	3·05	3·01
Feb.	18,849	3·05	2·80	1·89	Feb.	45,123	3·35	1·75	3·17
March	22,437	2·70	3·24	2·87	March	43,316	4·50	3·54	3·18
April	130,966	2·07	0·40	2·20	April	181,780	2·65	1·32	1·74
May	82,164	8·20	3·42	3·11	May	138,720	2·64	1·21	3·91
June	63,696	7·34	4·34	3·25	June	26,400	2·00	1·74	1·59
July	26,918	7·25	5·64	7·07	July	18,982	3·95	5·91	2·93
Aug.	59,996	12·79	7·35	5·28	Aug.	17,270	2·50	1·52	3·47
Sept.	53,388	3·48	2·62	6·20	Sept.	17,718	4·75	3·83	4·77
Oct.	41,923	2·47	1·57	3·64	Oct.	66,780	5·45	5·57	6·36
Nov.	62,897	5·05	0·75	4·48	Nov.	39,915	2·22	2·38	3·51
Dec.	45,548	5·00	2·27	2·69	Dec.	66,726	2·65	1·65	3·31
Total	638,070	61·35	37·28	44·19	Total'	727,160	40·51	33·47	40·95
1874.					1875.				
Jan.	135,491	3·70	2·90	5·46	Jan.	17,079	2·60	3·92	2·90
Feb.	96,674	1·80	1·81	2·18	Feb.	27,023	4·92	1·20	3·62
March	71,721	2·25	0·68	1·35	March	49,032	3·05	2·55	4·20
April	62,031	4·05	3·40	6·03	April	146,049	2·85	1·92	3·33
May	139,213	2·95	3·26	5·22	May	111,437	3·73	3·94	2·19
June	74,110	7·06	3·44	5·06	June	35,607	5·70	4·98	2·89
July	55,018	4·98	5·07	1·16	July	22,991	2·55	2·70	8·15
Aug.	28,293	4·38	2·01	2·69	Aug.	31,971	3·40	4·07	6·16
Sept.	17.412	1·35	3·92	1·82	Sept.	17,468	4·35	1·94	4·65
Oct.	19,310	1·15	1·30	0·85	Oct.	27,387	5·26	3·94	3·89
Nov.	15,865	2·71	1·92	3·54	Nov.	41,022	2·92	1·63	3·97
Dec.	17,965	3·07	1·08	1·17	Dec.	43,583	1·40	0·78	1·03
Total	733,103	39·45	30·78	36·53	Total	570,649	43·73	33·57	46·98
1876.					1877.				
Jan.	79,956	3·55	1·72	2·30	Jan.	17,500	2·15	2·70	2·52
Feb.	64,400	3·60	3·59	5·53	Feb.	18,491	0·65	0·00	0·36
March	93,866	3·02	3·50	7·10	March	93,253	6·40	2·57	6·97
April	160,756	2·75	0·52	3·10	April	110,247	2·35	1·97	2·45
May	155,521	4·70	1·32	3·96	May	45,374	1·05	1·03	1·93
June	41,008	7·05	3·46	3·87	June	20,907	3·00	4·07	4·59
July	22,016	5·25	0·00	4·84	July	25,475	4·22	8·48	6·47
Aug.	16,674	1·25	0·42	0·27	Aug.	22,946	5·95	4·01	2·79
Sept.	17,186	5·90	4·58	3·71	Sept.	18,089	2·05	0·91	0·91
Oct.	16,930	1·60	0·53	1·12	Oct.	31,772	4·70	4·67	6·98
Nov.	20,822	1·67	2·13	2·49	Nov.	75,825	3·65	3·81	5·44
Dec.	17,156	2·81	4·30	3·22	Dec.	46,382	1·87	0·96	1·02
Total	706,291	43·15	26·07	41·51	Total	526,261	38·04	35·18	42·43

At Norwich, on the west side of the Connecticut, opposite Hanover, th[illegible] precipitation in 1872 was 41 inches, in 873, 36·57 in 1874, 35·32; greater, i[illegible] each case, than at Hanover. Schott makes the annual *mean* at Hanover 40·66.

The number of inches of snow in the above years at Lunenburg and Hanove[illegible] was as follows:

Year.	Lunenburg.	Hanover.	Year.	Lunenburg.	Hanover.
1872	139·50	28·75	1875	122·45	106·73
1873	136·20	100·00	1876	90·85	113·00
1874	118·85	77·70	1877	42·75	32·00

loss were 340·6 cubic miles, the same work would have taken about 24 years.

8,215 cubic miles of ice are equal to the part of the glacier estimated to have occupied the drainage-area of the Connecticut at the time of maximum ice.

Supposing the above numbers approximately correct, we are still far from a knowledge of the time taken during highest flood for the disappearance of the ice from the valley. For in order to reach a conclusion it is necessary to know *also*,

(1.) The approximate amount of ice that was still in the valley when the epoch of maximum flood was reached, the estimate made being the amount at the time of maximum ice.

(2.) Whether the southward movement of the great northern glacier still continued, and was adding to the amount of ice.

(3.) What was the amount of ice contributed at that time by local glaciers within, or on the borders of, the drainage-area, which glaciers used some of the precipitation to make ice for melting.

(4.) Whether the melting, instead of continuing on uniformly, had its years or periods of interruption.

(5.) Whether the time of maximum flood was not quickly passed, even in one, two or three years, so that the discharge of the river was at its highest stage only for a very short time and rapidly declined to some limit, lessening thereby, both the rate of flow and the amount of water.

With doubts on points so important, this time-question must be set down as of impossible solution.

But while a definite answer is not to be expected, we may see reason for the following general inferences.

a. At the time of maximum flood the ice was not lying along the center of the valley producing the river by its gradual melting, and retreating northward as the river elongated in that direction.

The amount of water flowing off with a velocity of three or four or more miles an hour, making the great flood, was too vast to have been generated from a retreating body of ice in the valley.

b. If, as Greenland facts authorize us to believe, sub-glacial rivers of large size and energy were a universal feature of the Glacial era, these streams must have entered on a career of real progress when melting began in earnest. As they enlarged, the icy tunnels they had hitherto occupied would have become widened, and the sub-glacial chambers have extended themselves in all directions, undermining the heavy glacier. And as rapidly as this removal below went on, the deposition of the materials of the ground moraine—the stones, gravel, earth and clay—long before initiated—would have gone forward, covering with till the glacier-buried land. But, subsequently, when the rising streams had volume enough to make the lower range of terraces, along the valleys, the roofs of the tunnels were probably, for the most part, gone. The ice still lay over the land, covering deeply the hills and mountains, but the wide channelways were open to the day. Evidence of this is afforded by the fact that these lower terraces, like the higher, are free, with rare exceptions, from deposits or droppings of till or of bowlders, such as would have come from an overhanging glacier. But outside of the terrace plains, up the hill slopes wherever the ice still remained in force, the till may have continued to fall, adding later to earlier till. Other evidence that the streams, as the floods rose and terracing went forward, were free from ice overhead is afforded by the Lake Champlain and St. Lawrence valleys. The shell-bearing sea-beach deposits at Montreal and on Lake Champlain could hardly have been formed from a thriving growth of mollusks and other marine species while the glacier lay over the whole region to the Gulf, a distance from Montreal of 500 miles. Whales (*Beluga Vermontana*, resembling much *B. leucas* Gray), and seals, inhabitants of the bays of Arctic coasts, would never have made their way beneath such a cover of ice to Lake Champlain, a region also under the ice. If then the St. Lawrence valley for more than 500 miles and the Lake Champlain region were free of ice, this may also have been true of the larger valleys of New England and the west.

c. It follows from the existence of a cut across the glacier along the St. Lawrence valley, from Lake Ontario to the Ocean, over 500 miles from east to west, and north of all New England, that at the time of highest flood New England was not receiving additions to its ice through the southward movement of the great northern glacier.

d. The Connecticut valley, at the time of maximum flood, derived its waters—apart from the portion supplied by precipitation—from the ice of the bounding slopes of the valley and of the wide tributary region. Consequently, the melting surfaces up and down the borders of the valley and over the slopes east and west to the limits of the tributaries would have been of almost indefinite extent, and the ice thus melted might have reached the amount deduced above—a cubic mile per day.*

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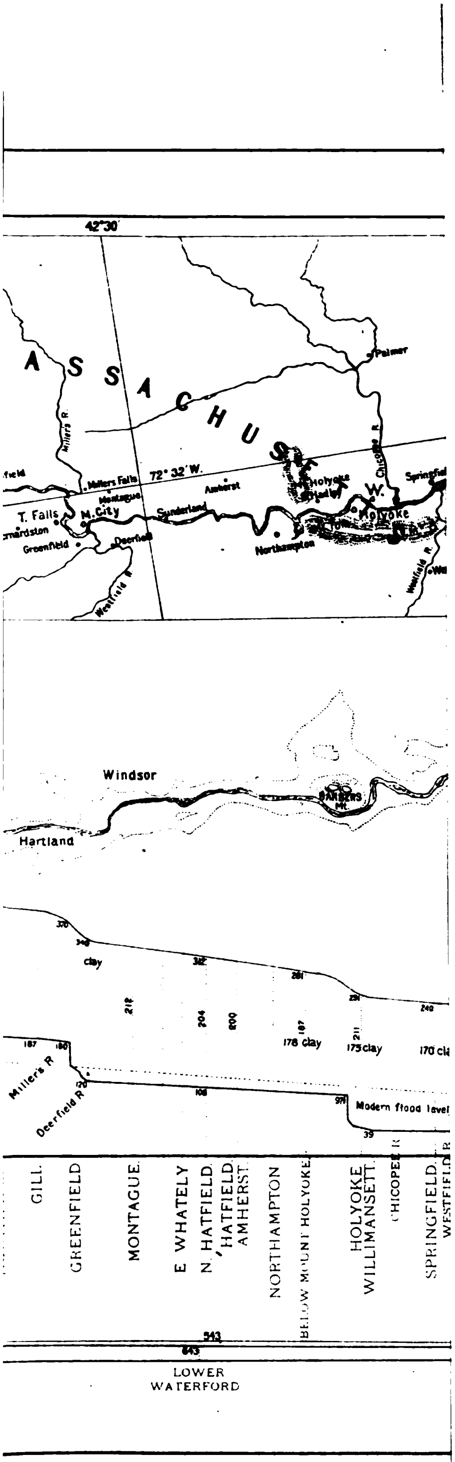
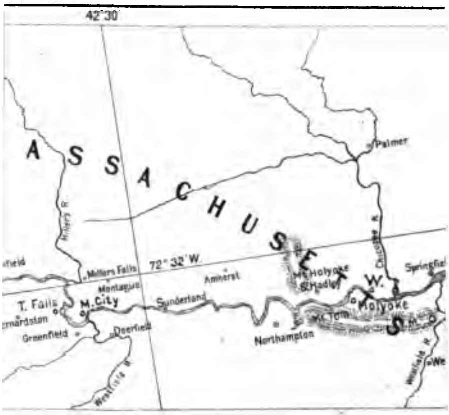
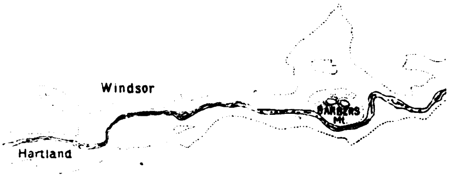
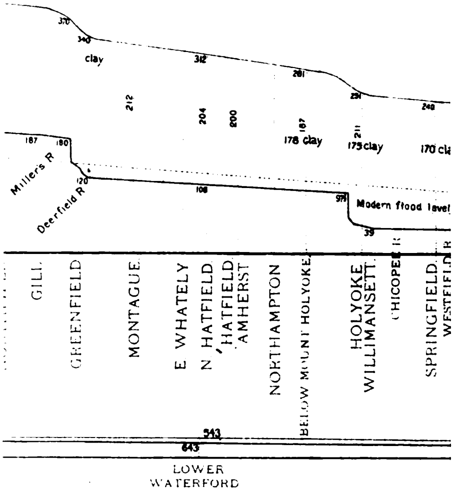
* It will be observed that such conditions were well fitted, especially toward the mountains or in the region of the upper sub-glacial portions of the tributary streams, to produce and set afloat masses of ice laden with till, to float down a tributary to the Connecticut—a kind of work that must have begun early in the era of melting. Reaching the wide borders or flood-grounds of this river, they would, for the most part, have been pretty sure to have become stranded above and below the mouth of the tributary, owing to eddies and shallows; and there, as they melted, would have dropped their stones and earth, and thus have helped to make the coarse gravel and cobble-stone beds which, in



HE MELTING GLACIER







HE MELTING GLACIER

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXIV, 1882.]

THE FLOOD OF THE CONNECTICUT RIVER VALLEY FROM THE MELTING OF THE QUATERNARY GLACIER.

THE QUESTION AS TO THE ELEVATION OF THE LAND.

BY JAMES D. DANA.

NOTE ON THE FORMER SOUTHWARD DISCHARGE OF LAKE WINNIPEG.

BY JAMES D. DANA.

[From the American Journal of Science, Vol. XXIV, August, 1882.]

ON

THE FLOOD OF THE CONNECTICUT RIVER VALLEY, FROM THE MELTING OF THE QUATERNARY GLACIER.

The Question as to the Elevation of the Land.

By James D. Dana.

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXIV, AUGUST, 1882.]

On the Flood of the Connecticut River Valley from the melting of the Quaternary Glacier; by JAMES D. DANA.

[Concluded from p. 373, volume xxiii.]

6. *The question as to the Elevation of the Land.*

THE remaining question in connection with the discussion respecting the Connecticut Valley during the era of the great flood is that relating to its apparent depression at the time:—Whether the change in pitch, which was proved to have been a fact, was due to a change in land-level, or only to a change in sea-level.

To understand the events of the Glacial era and that following and reason correctly on the facts, we should know which of these views is right, and, in order to know, take evidence from the region.

Toward this end, we may first compare the requirements of an hypothesis which refers the change to a change in sea-level with the facts observed. If the facts do not accord with the demands of such an hypothesis, we are then free to adopt the other view—that the depression of the land was actual and not merely apparent.

It should be understood, in advance, as a fact in terrestrial physics, that any rise in the ocean's level increasing northward produced by a change in the position of the earth's center of gravity would be,* effectively, a change (1) in the height of the land; and (2) a change in the pitch of its surface; and, New England, like the rest of the globe, being within the area so affected, it would be a change in pitch for the Connecticut Valley and the region around, as well as for the coast region. For, the ocean's surface is the reference-plane of horizontality as well as elevation, and the attraction determining its level would affect not only the land adjoining but also all instruments used over it for obtaining horizontal or perpendicular lines.

Only one source of a change in the position of the earth's center of gravity has been suggested in this connection—that from the forming of a polar ice cap of great thickness, during a glacial era in one hemisphere or the other, as in the hypothesis of Adhemar, adopted by Croll and others, this cause leading to an increased pole-ward accumulation of the oceanic waters in the ice-covered hemisphere.

The following are among the facts bearing on this subject.

(1.) There is no correspondence between the amounts of change deduced from observations and those required by the hypothesis. Since the amount of the apparent depression, that is, of the rise in the earth's curving water-surface which would follow from such a change in the position of the center of gravity, would increase northward very nearly in the ratio of the sine of the latitude, it follows that if the amount at Montreal were 520 feet, as the facts reported show, they should have been about 507 feet at Lewiston, Maine, 491 feet at Point Shirley, Mass. (near Boston), and 480 feet along the north shore of Long Island Sound. But, instead of the amounts 507, 491 and 480 feet the actual levels observed are 200, 75 or 80, and 25 to 15 feet.[*]

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* Assuming that the earth is so far rigid that it would not suffer deformation—or a depression of the crust—from the weight of the ice resting on its surface.

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Further, the hypothesis,—calculating again from the Montreal level, 520 feet,—would give hardly 730 feet for the region about the North Pole, and 720 for latitude 81° to 82°, or that of Grinnell Land and Northern Greenland; while in the latter region, Feilden and De Rance found sea-shells (*Pecten Grœnlandicus*, *Astarte boreale*, *Mya truncata*, *Saxicava rugosa*, etc.) in beach-made deposits at different levels up to 1000 feet.[†] But this is not all the divergence of the facts from Greenland terraces. For, in the part of Danish Greenland called Southern Greenland (between the parallels of 60° and 67° 40′), the part best known, no heights of terraces or elevated beaches have been reported above 350 feet. Dr. Rink, one of the Greenland explorers as well as Government Inspector for many years of Southern Greenland, mentions, in his latest work on Danish Greenland (1877), the occurrence, in this part of the semicontinent, of terraces at a height of 100 feet, rising in some places to 200 feet, and nothing of higher level. Mr. A. Kornerup, Geologist of Lieutenant Jensen's Expedition of 1878,[‡] observed terraces at several points, and describes a series, near the parallel of 63° 10′ N., to the north of Fiskernaes, the highest of which was 101 meters, and another in 63° 5′ N., of 106 meters (348 feet) as the maximum height. Nordenskiöld, in connection with his exploration in the vicinity of Jakobshavn, in 1870,[§] observed shell beaches up to a height of 100 feet near 69° 10′ N. Hayes, in his "Open Polar Sea," gives (p. 402) 110 feet as the height of terraces at Port Foulke, near 78° 10′ N., north of Cape Alexander. Kane describes, in volume ii of his Arctic Explorations (p. 80) a series of terraces in 78° 40′, the highest of which was 480 feet above the sea. Three degrees in latitude north of the last region occur the beaches at 1,000 feet, mentioned above. The discrepancy is thus increasingly great on going southward along the Greenland coast.

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[*] The height of the beds at Point Shirley is made 75 or 80 feet by Professor Shaler in his recent quarto volume on Glaciers forming the first volume of his proposed "Illustrations of the Earth's Surface."

[†] Quart. J. Geol. Soc., xxxiv. 563, 1878.

[‡] Meddelelser om Grönland, 196 pp. 8vo, Copenhagen, 1879.

[§] Geol. Mag., 1872, p. 400.

It may be said that the facts from Greenland are only partially known; and, again, that a depression is now going on in Southern Greenland which has increased, and may have occasioned, the discrepancy. But, connecting them with the facts from the Atlantic borders in more southern latitudes, the evidence against the hypothesis is decisive.

(2.) The idea of a polar ice-cap of the extent claimed is an assumption opposed to known meteorological laws and observed climatal facts. For the position of the region of maximum ice would have depended very largely on that of the area of greatest precipitation; and, as the writer, accordingly, some years since suggested,* and Mr. W. J. McGee has formally demonstrated,† the ice would have diminished toward the pole as well as to the northwestward. The eastern ice-range, located in this way between the Atlantic Ocean and points not far west of the Winnipeg line of lakes, 1000 miles in width at base, presented an immense surface for condensing the moisture of the Atlantic winds and diminishing the amount carried northward, so that the ice in Greenland would have had hardly half the height of that to the southwest, and more northern polar regions still less;—Mr. McGee's calculations making the thickness in Greenland in 60° N., 5728 feet, and in 70° N., 2800 feet, while south and southeast of Hudson's Bay on the Canada water-shed, it was probably not less than 12,000 feet.

In accordance with these conclusions, the ice, at the present time, is reported by Arctic travelers to be less thick in the northern part of North Greenland than in the part to the south, and also in the lands west of Greenland than on Greenland itself. Messrs. Feilden and De Rance (loc. cit., p. 567) speak of the paucity of glaciers in Grinnell Land, lying just west of Greenland, stating that north of 81° N. on this more western land, no glaciers descend to the sea-level although they do on the coast opposite of Greenland, the situation of Greenland against the Atlantic rendering it a region of more precipitation than that to the west; and so it would have been under the more favorable conditions for precipitation of the Glacial era. As to the height of the Greenland ice in the Glacial era we have the observations of Mr. A. Kornerup, of Jensen's Expedition,‡ that, near the parallel of 64° N. about the Ameralik and Buxe fiords, there are glacial scratches at a height of 1260 meters

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* This Journal, III, v, 206, 1873, ix, 312, x, 385, 1875, xiii, 79, 1877, xv, 250, 1878.

† Proc. Amer. Assoc., xxix, 1880, on Maximum Synchronous Glaciation; a portion of which paper on the particular point above referred to is cited in vol. xxii, of this Journal, p. 264 (1881). Mr. McGee gives for the thickness at 50° N. only 8213 feet.

‡ Loc. cit., pp. 109–113.

(4134 feet), a level almost 3000 feet above any glaciers now in that vicinity, and near the parallel of 63° N., in the vicinity of Kuvnilik and Björnesund, at heights of 940 to 1100 meters (the latter 3609 feet); but none on the upper part of Nukagpiarsuak, northwest of Kuvnilik, whose height is 1520 meters (4987 feet). Mr. Kornerup also states that in the era of extreme glaciation when the glacier was 3000 feet higher than now, the movement of the ice was nearly *east-and-west*, but subsequently, as the scratches at lower levels show, it followed the direction of the fiords or valleys:—a change evidently due to the thinning of the ice, the pitch of the upper surface being great enough when the glacier was at its maximum to cause ice to move independently of the courses of valleys or depressions beneath, and not so after the thickness had been much reduced. This fact had its parallel all over glaciated North America.

(3.) In addition, the hypothesis makes the submergence of the Coast region (indicated by elevated beaches) to have taken place *during the Glacial period, and to have passed its maximum in the height of the period;* when, according to the facts, whatever the condition in the Glacial era, the submergence was a prominent feature of the era when melting was going forward and the ice finally disappeared—the Champlain period. This point needs no special remark after the descriptions already given of the Connecticut River terraces, and the explanations in the following part of this paper.

(4.) But the Glacial era was not for the higher latitudes generally one of *less* elevation in the land than now, and was probably one of somewhat greater elevation for large portions.

The arguments in favor of such elevation I here briefly review, in order to test them by a reference to recent discoveries.

(*a*) One of these arguments is based on the depth to which many river channels are excavated below the present bed of the stream. It has been strongly urged by Dr. Newberry and others. The facts supporting it have been drawn from New England and the States of New York, Pennsylvania, Ohio, Indiana, Illinois, Wisconsin, and from British America; and new cases are annually becoming known. The Pennsylvania Geological Report for 1881 by Mr. I. C. White, treating of Erie and Crawford Counties (among the western counties of the State), remarks that a boring for oil on French Creek, below Meadville, descended *for* 285 *feet through the drift;* and another, in Conneaut Creek valley, 180 feet in drift; and in connection with his account of these and other cases, he speaks of it as a general fact that "the present water courses meander along the upper surfaces of drift-deposits which fill the ancient valleys to various heights above the old rock beds." Other similar facts from western Pennsylvania are presented in the report of Mr. J. F. Carll, for 1880. During 1881, Mr. J. W. Spencer published facts respecting a buried channel between Lake Erie and Lake Ontario, which entered the latter lake along the steeply escarped Dundas Valley.* He states that in this valley the drift has been penetrated to a depth of 227 feet below *the level of the lake* without reaching a rocky bottom, and that the depth of the drift is probably as much as 1,000 feet. He also points out that the channel of Lake Ontario, which has its greatest depth abruptly near the southern side and gradually shallows northward, is a channel of erosion and probably of cotemporaneous erosion with that of the Dundas Valley.

Reported examples of this kind are so numerous that they are regarded now as representing a general fact. Such excavations could not have been made by running water while the land was at its present level; and much less could they have been made when the land was lower than now. Their origin was hence before the Champlain period in *Glacial* or *pre-Glacial* time.

The accounts speak of these deeply-eroded valleys as filled with *drift;* and if with true *northern drift*, as is implied by the language—a point which in all cases needs special examination—they were open to their bottom to receive the drift during the Glacial era. For otherwise they would be found filled in each case with the sand and gravel of the drainage-area instead of with material from a more northern source. And if open in the Glacial era, the land was at a higher level than in the Champlain period, or that of great deposition; high enough for a flowing stream to have kept the trenches clear of deposits. Many of these valleys, like that of Dundas Valley, have a different course from that of the movement of the glacier, and hence, no aid could have been afforded by the glacier in the excavation if the level was as now; and the aid would have been ineffectual whatever the course.

The facts thus prove that if the material filling these buried valleys is true drift, the land in the Glacial era was higher than now; and *much* higher, if the drift of the Dundas Valley is 500 to 1,000 feet deep. The valleys may have been pre-Glacial in origin, but their depth would have reached its lowest limit from the latest erosion or that of the Glacial era.

The argument from the deep river-made channels intersecting sea-border regions, and now occupied by the sea—that is from long bays and fiords 100 to 3,000 feet or more in depth of water—which characterize the shores in the higher latitudes on all the continents, north and south, still stands good so far as this at least, that if, as is probable, antedating in first origin the Glacial era, the final deepest erosion took place at that time. Being proof of water erosion, they are proof of the emerged state of lands where now are seas 1,000 to 3,000 feet deep. But they do not prove that there may not have been several successive emergences and Glacial eras concerned in their production.

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* Proc. Amer. Phil. Soc., 1881, and Proc. Amer. Assoc. Adv. Sci., 1881.

(*b.*) Again, there are deserted water-courses which appear to owe their desertion to a change of level which took the flow from the waters. In many cases the desertion was due simply to a decline of the flood, and a filling of channels by the depositions. But in other cases, like that of the discharge of the St. Lawrence from the Great Lakes, an appeal to diminished southward pitch in the land is necessary to account for the depositions of the Champlain period, and also for the present condition of the lakes as to outlet.

(*d.*) An argument for the probability of a greater elevation in the Glacial than Champlain period I have based, in earlier papers, on the progressive elevation of the continent which was going on during the preceding Tertiary era; and this has lost none of its force by recent discovery. The elevation of the Rocky Mountain region from Mexico on the south to the Arctic seas, and which amounted to 10,000 and 11,000 feet in the higher portions of the United States, was not completed until the close of the Pliocene—the vast Pliocene fresh-water lakes proving this; and the close of the Pliocene was the beginning of the Glacial era. Besides this upward movement in the western two-thirds of the continent, a smaller took place in its eastern portion, as geologists have inferred from the absence of marine Tertiary either above or at the sea-level north of Cape Cod, and of Pliocene Tertiary to a large extent south of it. Thus the Tertiary changes of level were, in the main, upward to the end of this age.

It is evident, too, that these changes of level in the Tertiary were changes of land-level. For changes due to a transfer of the ocean's water meridionally would have been alike on the two sides of the continent.

It is deserving of consideration also that an elevation of large portions of the Arctic regions would be favorable to the production of Glacial conditions, for it would diminish the depth of the arctic seas, and consequently would diminish the volume of arctic currents flowing southward, and of tropical waters reaching the arctic; and it would hence increase the cold of arctic seas and lands and of the lands south, and the warmth and rate of evaporation of the North Atlantic in temperate latitudes.

The evidence reviewed thus shows that there were real changes of land-level and not simply a change of ocean-level connected with the coming on and disappearance of the ice of the Glacial era; and that the level during the Glacial era was not below the present, like that of the era following, but at least as high as the present, and probably, in many portions of the colder latitudes, somewhat higher than now.

It thus follows that a change of level of very wide continental range introduced the era of depression or Champlain period—a change so great and so marked in its effects that it is reasonably recognized as a time-boundary in Quaternary history; and as the Champlain period was one of ameliorated climate, it may have begun with the beginning of the melting. As I have shown in the earlier part of this memoir, the depression was certainly a fact during the great flood, and began before the melting had far advanced. The fact of a warmer climate in the Champlain period is manifested in the distribution of the quadrupeds and forest trees of America, Europe and Siberia, as now generally admitted. It is most strikingly demonstrated among the lands of the Arctic seas, where, on Banks's Land (74° 48′), Prince Patrick's Island (76° 12′ N.), and elsewhere, unaltered trunks of modern fir trees, single and in forest-like accumulation, exist.

But the facts as to amount of change of level are not so well known that we can mark off the limits of the areas of elevation and depression over the higher latitudes. They do not enable us to decide whether there were not, extending northward, a series of upward and downward flexures, with only a greater general emergence than now in the Glacial era and a greater general submergence in the era following. The heights of terraces on the coast of Greenland seem to be an indication as to one in this series of flexures. In any case the facts do not sustain the ordinary assumption that the amount of depression in the Arctic regions was approximately alike in all parts, and they leave it to be proved that all portions participated in the subsidence.

The cause of the depression of the land, or of the previous elevation, this is not the place to consider.

[From the American Journal of Science, Vol. XXIV. December, 1882.]

NOTE ON THE FORMER SOUTHWARD DISCHARGE OF LAKE WINNIPEG.

By J. D. Dana.

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXIV, DECEMBER, 1882.]

Note on the former Southward Discharge of Lake Winnipeg; by J. D. DANA.

THE most remarkable of the changes that are known to have occurred in the water-courses of North America is that in the discharge of Lake Winnipeg from a former southward course by the Minnesota Channel and Mississippi to its modern discharge into Hudson's Bay, first announced and sustained by General G. K. Warren, in a report of 1867 published in the Report of the U. S. Engineers for the year 1868 (pp. 307–314), after levelings along these rivers, by order of the government, in 1866 and 1867. The question was more fully illustrated by General Warren in "an Essay concerning important physical features exhibited in the Valley of the Minnesota River and upon their signification," submitted to the Chief of Engineers in 1874 and published in the Report for 1875 (pp. 385–402); and afterward, further discussed by him in his paper on the Bridging of the Upper Mississippi, in the Report for 1878 (pp. 909 to 926) with a reproduction of some of the maps of the essay of 1874. The last of the above-mentioned papers, excepting its closing details as to sections across the valleys, is reproduced in this Journal on pages 417–431, vol. xvi, 1878, along with its eight maps and plates.

In the first of his papers, that of January, 1867, General Warren, after mentioning the evidences that "Lake Winnipeg was once continuous southward over the central portion of the Red River of the North, and had its outlet down the Minnesota, and not down the Nelson to Hudson's Bay" (p. 307), considers the origin of the former hydrographical conditions. He speaks of the possibility of an ice-barrier on the north in the Glacial era; but he sets this idea aside, and argues for an actual change of land-level, and makes the southward discharge to have ended in consequence of a depression of land to the south, accompanying (as added in his paper of 1875) a rise to the north; and instancing, as examples of a corresponding change of level, the former *southward* discharge of Michigan Lake through the Illinois River, and of Winnebago Lake through the Wisconsin River. A map of the large Winnipeg Lake—larger he observes than Lake Superior and Michigan together, and having the Saskatchewan River as the head stream—accompanied the written report sent to the Department, but it was not published. The same view is presented at more length in the paper of 1874 (Report for 1875), along with a wider discussion of the facts, and a review of the writings of previous travelers who had recognized the lake-like features of the region.

The idea of the southward discharge of Lake Winnipeg was presented again in 1875 by Mr. George M. Dawson, in his excellent Report on the Geology of the region in the vicinity of the 49th Parallel, with a recognition of General Warren's paper, but with the statement that the inference was an independent one. In explanation, he says (pp. 253, 254) that "by the flow of a large volume of water in this direction, the excavation of the basins of the Winnipeg group of lakes and the great valley of the Red River itself can be explained; the river cutting downward and westward on the sloping surface of the Laurentian rocks, at the expense of the Cretaceous strata, and later of the limestones of the Devonian and Silurian; the blocking up of the southern exit and changed direction of flow being a phenomenon only similar to that which is known to have taken place with the Great Lakes of the St. Lawrence."

The ice-barrier hypothesis has been sustained, in place of that of a change of level, by Professor N. H. Winchell in his Minnesota Report for 1877, who there observes, in his explanation, that the lake, having first appeared at the south or Minnesota end, "grew toward the north as fast as the retreating ice-sheet made way for it." In the Minnesota Report for 1879, the same view is urged, with more detail, by Mr. Warren Upham.

A decision between these two conflicting explanations is of great importance to a right understanding of Quaternary events as well as of fundamental principles in terrestrial dynamics; and I therefore review here the more prominent facts, taking them mostly from General Warren's papers and the Report of Mr. Dawson.

1. The Red River of the North, rising in Lake Traverse, flows northward along the west side of Minnesota for 225 miles, crosses then the 49th parallel, and continues on the same course

for 90 miles to Lake Winnipeg; the distance from Lake Traverse to Lake Winnipeg being 315 miles.

2. The Minnesota, rising to the westward of Lake Traverse, enters its valley within two miles of it and flows south, through Big Stone Lake, to the Mississippi at Minneapolis.

3. The valley of Red River, after narrowing much, is still 46 miles wide on the 49th parallel, and, for a long distance south of this parallel, it has an average width of 30 miles (Gen. Warren's map and G. M. Dawson's statement); toward Lake Traverse it narrows rapidly, is a mile wide along this lake, the sides rising abruptly from the borders of the lake; beyond this lake, southward, it continues on, one to two miles wide, as the valley of the Minnesota River; and, where it joins the Mississippi, the valley has four times the width of the Mississippi valley above the junction (Gen. Warren).

4. All now agree that the wide part of the valley which stretches northward from Lake Traverse is lake-bottom prairie, that it was adopted by the Red River, not made by it (Dawson); and that the part south of this lake, is, as General Warren first showed, the deserted highway of the outflowing river and lake.

5. The Red River lake-bottom valley is bordered much of the way by abrupt sides rising 100 to 200 feet to the top of a terrace-plain or plateau; and, similarly, the Minnesota channel has sides usually 100 to 150 feet in height.

6. Heights above the sea-level:

(B. C. means Boundary Commission Report.)

	1. Lake-bottom prairie.	**2. Bordering plateau.**
Near 45° 30′ N., between Big Stone Lake and Lake Traverse (5 miles apart),	970	1,120
Near 47° N., at Fargo and Moorhead,	900	1,050 (?)
On the 49th parallel near Pembina and St. Vincent,*	784 (B.C.)	**East side 989** **West side 994**
Toward Lake Winnipeg,	740	810

Height of Lake Winnipeg (about the mouth of Red River, a great marsh), 710 feet.

The heights on Minnesota River are (Winchell's Report):

Surface of bordering plateau near Big Stone Lake,	1,125
At Mankato, 145 miles south,	975
At Shakopee, 50 miles northeast,	925
At junction with the Mississippi,	800 to 820

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* The height of the Lake of the Woods is 1048 feet (B. C.); of the divide between it and the near-by head of Roseau River, a westward-flowing tributary of Red River along the 49th-parallel region, about 1078 feet (Dawson); edge of plateau where it looks down on the lake-bottom about Pembina, 90 feet less (B. C.), and hence about 988 feet: Pembina Mountain, on the west side, 210 feet above the lake-bottom prairie, and hence 784 + 210 = 994 feet above the sea-level. Red River as it flows in its channel is 20 to 60 feet below the surface of the lake-bottom prairie; at Pembina, about 50 feet (Warren).

7. The *slope* of the lake-bottom prairie is *northward*, toward Lake Winnipeg; and, from the 49th parallel, according to Dawson, it is nearly six inches per mile; the mean slope from Moorhead in Minnesota, 150 miles south of the 49th parallel, is little less than one foot per mile.

The slope of the bordering plateau *northward* from Lake Traverse to Lake Winnipeg, 315 miles, is about one foot per mile; for 1,125−810=315.

The slope of the bordering plateau along the Minnesota from Big Stone Lake to Mankato (145 m.) is *southward* and about one foot per mile: for 1,125−975=150.

8. The material of the lake-bottom, where examined by Mr. Dawson, is mostly yellowish clayey earth or lœss, containing calcareous matter enough to effervesce freely with acids; the upper portion is rarely so coarse as to be called sand, though sometimes an arenaceous clayey material; that of the border is also somewhat arenaceous. The depth of this lake-bottom deposit is generally 40 feet or more over the central portions, but it thins toward the sides. This point is illustrated in the plate facing p. 248 in Dawson's Report. He represents the lœss as overlying stratified drift and bowlder clay. The surface of the prairie rises somewhat toward the sides; but whether the depression is more than would result from the drying (and consequent contraction) of so much wet loam after the disappearance of the lake, is not ascertained. It is rare to find anything like pebbly areas or pebbles over it.

9. The outline of the lake-bottom prairie has the appearance of being, so far as it extends, the outline of the great Winnipeg Lake, and is so recognized by Warren, Dawson and others.

10. The material of the bordering high plateau along both the Red River portion and the Minnesota is coarse gravel and sand; much of it unstratified till, much, more or less stratified; and the upper surface is often pebbly or stony, with occasional bowlders.

Roseau River, for 25 miles east of the western edge of the plateau, says Dawson (p. 214), has cut deeply into the plateau formation so as to have high bluff sides; and the sections show alternating beds of clay, sand and gravel characterized by "current bedding;" one of them having stratified arenaceous clay below, then coarse gravel, then sand, and then gravel as the top beneath the soil; another "typical one" consisting of hard-compacted clay below, partly stratified, then a thin pebbly bed, then sand, then the upper gravel. These are given by Mr. Dawson as examples of the constitution of what he calls the "Drift Plateau of Eastern Manitoba and Northern Minnesota." He says of the great "High-level Plateau" that it is frequently irregular in detail, covered with banks and ridges of sand and gravel of the nature of "kames," but, on the whole, remarkably uniform; on the 49th parallel it rises gently eastward toward the Lake of the Woods, 90 feet in the 77 miles. On the upper part of the Minnesota the deposits are largely the Glacial drift (General Warren, and Professor Winchell), with also portions that are bedded.

Conclusion.—Taking the accounts of the region from which we have cited to be correct, we have the deduction forced upon us that Winnipeg Lake did not lose its discharge into Hudson's Bay and become the great lake with southward discharge, because of a barrier of ice or of any other kind. For if so, if there had been no great change of slope over the region, the shores of the *great* lake should be approximately horizontal, to its outlet at Lake Traverse, and if horizontal, they would have a height in the vicinity of the present Winnipeg of 260 feet above the lake, supposing the waters just up to the Lake Traverse level, and 300 feet if the water at this place of discharge was merely 40 feet deep. Instead of this condition, *the observed shore line has nearly the present general slope of the surface;* and, further, *the slope of the lake-bottom prairie is not much different from that of the bordering plateau on either side.*

We have thence the conclusion, since the present outline of the lake-deposits or lœss, whatever the present slope, was approximately the shore-line and once horizontal, that there has been a great change in the level of the land, as General Warren urged. The idea of a change in the position of the earth's center of gravity sufficient to change the slope of the surface a foot a mile, or half a foot, cannot be reasonably entertained.

We may infer also, from the near correspondence between the northward slope of the lake-bottom prairie and that of the bordering plateaus, that the prairie and plateaus were affected alike by the conditions as to level. And we may deduce from the regularity of the slope, that the conditions as to level affected equally the region from Lake Traverse to Lake Winnipeg, and beyond doubt also to a much greater undetermined distance northward.

This conclusion bears so profoundly on questions as to the condition of the earth's interior, and the origin of changes of level over the earth's surface, that it is greatly to be desired that further investigations should place the facts beyond all doubt.

Admitting that the facts are correctly given, they appear to point to the following succession of events:

The fact that the lake deposits are underlaid by unstratified drift, shows that before the era of the great lake the glacier had moved southwestward over the region, and deposition of moraine material had taken place. The high-level prairie either side of the lake region and of the Minnesota valley is made largely of this unstratified drift; but the generally level surface in the part toward the lake region and valley, and the stratification in much of the material, are evidence that the flood from the melting glacier covered and levelled it, and stratified its bedded deposits; the coarseness of these deposits, and the large size of the valley of discharge, that the flood waters had great velocity; the height of the prairie, that they stood 100 to 150 feet above the present level of the region including Lake Traverse, instead of the 40 feet at the divide above supposed. This time of maximum flood and of rather violent fluvial conditions was followed by the era of the Great Lake, that is, of quiet waters and lacustrine deposits, with slow discharge over the Lake Traverse region: which may have been brought about in part by diminished supply of waters from the melting ice and precipitation, but more, with little doubt, by a diminution in the slope of the general surface, which was a part of the great change of slope that went on, as explained by General Warren, until the land was reduced to its present pitch and the streams to their modern courses.

The application of a new name, Lake Agassiz, to the flooded Lake Winnipeg, proposed by Mr. Upham because of its alleged relation to the retreating ice-sheet, tends to obscure the great historical facts in the case. All desire to honor Professor Agassiz, and no one more so than the writer; and still the name that most deserves honor in connection with the developments in Central North America is that of General G. K. Warren. But rather than use either, it is better to let the accepted name, Lake Winnipeg, be the name for past, as it is for present, time.

[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXV, JUNE, 1883.]

ART. XLVII.—*On the Western discharge of the flooded Connecticut, or that through the Farmington Valley to New Haven Bay;* by JAMES D. DANA.

THE discussion with regard to the flooded Connecticut requires for its completion a revision of the facts with respect to the Farmington valley discharge, presented in my paper of 1875.* It was there shown that the height of the flood from Northampton southward, as indicated by the terraces, was great enough for the waters to have passed the Hampton "divide" between Northampton and Westfield, and the Southwick, between Westfield and the Farmington valley; that they had a height of about 270 feet above mean tide at Simsbury (130 feet above low water in the river), and 223 feet at Southington (85 above low water); and that, from this latter place, while the rapidly descending Quinnipiac valley gave the most obvious way for the waters to New Haven Bay and Long Island Sound (the mean pitch in the sixteen miles being over nine feet a mile), the level over the Cheshire region and along Mill River was low enough to have afforded a shallower passage-way, and one more directly southward, to the same bay. The Quinnipiac River where the stream turns eastward to leave the Farmington Valley, below Hough's Mills, is at the present time only 100 feet above mean tide, there being a fall of nearly forty feet from Southington; while the head of Mill River in Cheshire, about three miles distant to the southwest, is fifty-five to sixty feet higher; and hence the Quinnipiac was supposed at the time to have taken the most of the waters if not all.

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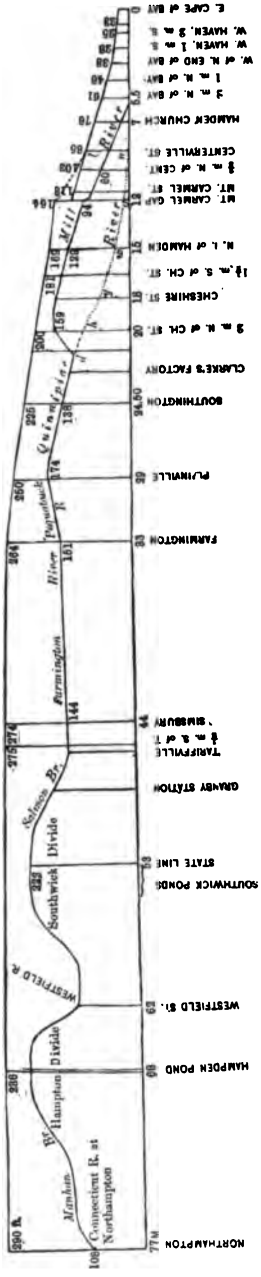
* On the Overflows of the flooded Connecticut, III, x, 438.

The map of the Connecticut River region, in vol. xxiii, Plate 2 (1882), shows the country and its streams from Northampton along the Farmington Valley and the Quinnipiac and Mill Rivers to New Haven. For the convenience of the reader, the map of the two regions which was published in the paper of 1875 is reproduced as Plate 5 in this volume.

In order to complete a profile of the flood, it became necessary to make new measurements, and also to settle the rival claims of the two streams, the Mill and the Quinnipiac. Unexpectedly little Mill River was proved to have taken all the waters of the Farmington valley when the flood was at its height.

This fact was proved by (1) the continuation of the high terrace of the Southington region over the Cheshire region, along Mill River as well as the Quinnipiac, in spite of the lower position and offers of drainage of the Quinnipiac water-way; (2) the high water level (164 feet) indicated on the Mill River valley south of Cheshire at the Mount Carmel gap; (3) the cobble-stone coarseness of a large part of the stratified valley deposits from Southington southward over the Cheshire region and thence all the way down Mill River valley to New Haven Bay; and then, in contrast with these evidences of high and violent flood along the Mill River route, (4) the very low terrace on the Quinnipiac, as it enters the Meriden valley above Hanover Pond, and (5) the generally sandy nature of the terrace deposits in this part and to the southward along through Wallingford where the sands make barren sand-fields, and beyond to New Haven Bay.

It is plain that the Quinnipiac channel was closed by a dam, probably an ice-dam. The river now leaves the Farmington valley by a gorge that goes eastward through high sandstone hills, and after more than a mile in the gorge or cañon enters the Meriden valley. The gorge was easy of obstruction by



Section of the overflow flood of the Connecticut from Northampton to New Haven: the lower line, mean-tide level; the middle line, low-water level in the streams over the land that was covered by the flood; the upper line, the upper-terrace level and approximate height of flood. *d*, Hough's mills; *h*, head of Hanover Pond; *y*, Yalesville; *w*, Wallingford; *q*, Quinnipiac Factory; *n*, North Haven.

floating ice, and so the river lost its head. Below the gorge it had to begin anew, with waters from slopes about the latter region, receiving from its former source only what leaks in the dam let through, and hence the terrace also began anew, and was necessarily small. On the other hand to the west of the obstructed gorge, the Farmington flood kept on a straight course to Long Island Sound.

The accompanying profile of the river-flood from Northampton by the Farmington and Mill River valleys to New Haven exhibits the facts to the eye—though with a large exaggeration (nearly 160 times) in the height as compared with the length, an inch horizontal corresponding to twelve miles, and the vertical to 400 feet. The *upper line* shows the height, along the route, of the upper terrace, and thereby approximately that of the flood; starting at 290 feet above mean tide about Northampton, it passed the "divides" with a depth of more than fifty feet and ended at New Haven Bay with a height of about twenty-five feet above present mean tide. The *line next below* is that of low water in the streams. The *lowest* line is that of existing mean tide level; the figures under it give the distances measured along the valley from the east or Light-house Cape of New Haven Bay; and the lettering below, the names of the principal places along the route where the observations registered were made, with their distances from this cape.*

I. *Section from Northampton along the Farmington, Quinnipiac, and Mill Rivers to New Haven and Long Island Sound.*

	Distance from Sound in miles.	Upper terrace above mean tide.	Low river level above mean tide.	Upper terrace above low river level.
Northampton	77	290	108	182
Hampden Pond	68	286		
Hampton Pl'n ("divide")	64	[249–256]	231	
Westfield	62		122·4	
½m. S. of Tariffville	45·5	275	143·5	131·5
Simsbury	44	274	144	130
Farmington	33	264	151	110
Plainville	29	250	174	76
SOUTHINGTON	24·50	225	138	87
2m. N. of Cheshire St.	20	200	159	41 to W.† 104 to E.
1⅓ m. S. of Cheshire St.	16·50	181	142	39
N. line of Hamden	15	169	129	40
Mt. Carmel gap	12	164	94·5 to 82·5	69·5
Mt. Carmel Station	11·50	118·5		36
⅜m. N. of Centerville	10	103	60	43
Centerville Station	8·75	88	38	47
Hamden M. E. Church	7	76		50?
2m. N. of N. H. Bay	5·5	61	tide level	
1m. N. of N. H. Bay	4·5	48		
W. of N. end of Bay (N.)	3·5	38		
W. Haven, 1m. S. of N. end of Bay	2·5	28		
W. Haven, 2m. S. of N. end of Bay	1·5	25		
W. Haven, 2½m. S. of N. end of Bay	1·0	23		
Lighthouse Point E. Cape of Bay	0			

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* The height of the terrace at Hampden Pond is from a valuable paper by Mr. J. S. Diller, published in this Journal in 1877, giving careful measurements of the terraces about Westfield and the "divides" north and south. He states that on Westfield River, sixteen miles west of the village, the highest river terrace is 289 feet above sea-level; and that, allowing for the most probable slope in the stream, the height over Westville village is probably not less than 280 feet. (This Journal, III, xiii (1877), 262.)

The heights of the terraces south are from my measurements, for which I used as a base the levels of the New Haven and Northampton railroad, received from the engineer of the road. These levels above mean tide are as follows: at Mt. Carmel Station and Gap, 132 feet; at N. line of Hamden, 135; Cheshire Station, 165; 2 m. N. of ibid., 163: Hitchcock's, 164·5; Southington, 145·76; Plainville, 187·5; Farmington, 241; Allen's Station, 277; Avon, 201; Simsbury, 164·25; surface of Southwick Ponds, 222·11; surface of Hampden Pond, 248·27.

† "To W." signifies above the level of low water on the Cheshire or *western* side, and "to E." above the same on the Quinnipiac or *eastern* side, just below Hough's mills.

The heights are also given in the preceding table, in which the first column contains the distances from the east or Lighthouse Cape of New Haven Bay; the *second*, the heights of the upper terrace; the *third*, those of low-river levels, above mean tide; and the *fourth*, the height of the upper terrace above the low-river levels.

The above profile shows also, by means of a dotted line (*d*, *n*) the descent by the course of the Quinnipiac valley. On this stream tide-level is reached at North Haven.

A second table is here added, to present in figures the heights of the terrace-deposits and river from Southington, southeastward and southward, by this latter route.

II. *Section from Southington along the Quinnipiac to Fair Haven (E. of New Haven).*[*]

	Distance from Sound (northings) in miles.	Upper terrace above mean tide.	Low river level above mean tide.	Upper terrace above low river level.
SOUTHINGTON	25·25	225	138	87
1·6 m. S. of Southington, at Atwater's factory..	23·60	207	129	78
2·05m. S. of Southington, at Clarke's factory...	23·20		120	
½m. N. of Hough's mills	20·75	200	102	98
Hough's mills below dam	20·25	200	96–95	104–105
Head of Hanover Pond.	19·75	105	86	19
Foot of Hanover dam..	19·75	105	69	36
Ab. Yalesville, Sanford's factory	18·33	96	52·5	43·5
Yalesville, Parker's fact.	17·67	93	49	44
Wallingford...........	15	76	13	63
Quinnipiac factory	13·25	68	5	63
North Haven..........	10·25	60	0	Ab. mean tide. 60
½m. N. of Montowese R. R. station	7·75	52	0	52
Junction Hartford and Air Line R. R.	5	49	0	47
Fair Haven R. R. and Perkins St. crossing..	4·5	43	0	43
E. Cape of Bay........	0			

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[*] The heights of the terraces here given were obtained by leveling from the surfaces of the mill-ponds as a base, the heights of the mill-ponds having been determined from the heights of the dams and the fall of the river between them, obligingly obtained for me by Mr. S. C. Pierson, Civil Engineer at Meriden. The heights of low water are heights to the base of the dams. The heights of these dams are as follows, commencing to the south: the Quinnipiac, on the south boundary of Wallingford, 6 feet; the lower dam at Wallingford (Wallace, Simpson & Co.), 10 feet, the upper, or Community dam. 8 feet; below Yalesville (A. J. Mix's), 10; at Yalesville (Parker's), 10; near Yalesville R. R. station (Sanford), 7; Hanover, 17; Oregon dam (in the gorge between Hanover Pond and Hough's mills, but now destroyed), 6; Hough's mills, 6 feet. Hanover Pond was proved by Mr. Pierson, by leveling from Meriden, to have a height above mean tide of 86 feet, the height of the track of the railroad at Meriden station being 124·63 feet.

The profile and the tables with the other observed facts make manifest:

First. The fact of the Quinnipiac dam, as already explained; the *first* table showing a gradual decline in the heights of the upper-terrace level from Southington through Cheshire; and the *second*, the continuation of the high-level Quinnipiac terrace of Southington to Hough's Mills, or 4½ miles, where the terrace has a height of 200 feet and is one and the same with that of Mill River; then a drop down of 95 feet, the terrace just above the head of Hanover Pond having a height of only 105 feet above mean tide, and but 19 feet above low water in the stream.*

(2.) *Secondly, the existence of a dam at the Mt. Carmel gap and of a sluice-way at its western angle.*—The water-level at the gap, as the profile and tables exhibit, was at least 164 feet above mean tide. From this level there was an abrupt plunge or water-fall, of about 45 feet; for the highest terrace of the flat region directly south is but 118 to 118½ feet, which terrace bears evidence of being the upper in the valley, in that it is continued on as the upper, with gradual slope, to New Haven Bay. The water-fall is indicated in the section, page 442, under the number 164.

The height of the terrace two miles north of the gap is some indication as to flood-level at the gap. But direct evidence is afforded by deposits of very coarse gravel, partly cross-bedded, near the top and under the lea of the western trap ledge of the gap; and also (2) by the continuation of these deposits southward, many of the stones of which for the first mile are one to three feet in diameter, all well smoothed and *none scratched;* and (3) by the existence of remains of a great well-smoothed trough or sluice-way, about 30 feet wide, in the sandstone, which was the work evidently of a violent torrent, several long oblique recesses on its sides, one to three feet broad, being marks of its *revolving* flow; the smoothed surfaces are nowhere scratched, and in this and other ways show that they are not of glacier origin.

The accompanying figure is a profile of the gap, with the height exaggerated only two times. Mt. Carmel (on the east) is an east-and-west ridge, chiefly of trap, 739 feet in greatest height above mean tide. It is the eastern portion of a range of trap and sandstone which continues westward to the West Rock trap range. The gap is about 250 yards wide; but it is partly obstructed by ledges, and Mill River occupies only 100 feet of its breadth. The waters of the sluice-way flowed out (at H) west of the summit of the western of these ledges (C); the lowest level over which at H is now 164 feet. The stratified gravel referred to as under the lea of this ledge (visible from the railroad cut R) has a height of about 152 feet; and the upper limit now visible of the excavated trough or sluice-way near the Mt. Carmel station, half a mile south of the gap, has a height of 145 feet. This trough or sluice-way in the sandstone was uncovered in grading for a new lay-out of the railroad, it offering the lowest level for the track. It can be traced along the course of the railroad for 200 yards below the station; it then passes to the westward of the road and becomes the head of a partly cobble-stone paved valley whose stream joins Mill River at Centreville (see section). The sluice-way torrent must finally have worn away part of the east side of the trough and so made a passage into Mill River valley. The height of the trap at D above mean tide is about 240 feet.

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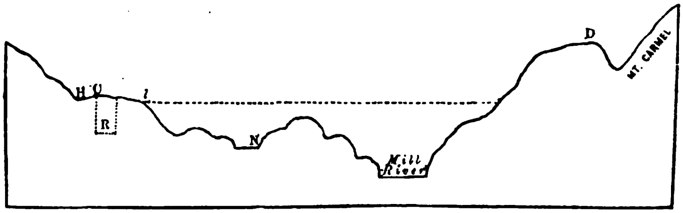
* Going southward from Hanover Pond (southwest of Meriden), the terraces of the Quinnipiac increase in height and become between Wallingford and Fair Haven 40 to 52 feet; this increase was due to tributary waters from the direction of Meriden, and the divide between Hartford and Meriden. In my paper of 1876 I point out the fact that the Connecticut flood waters overtopped this divide. The divide has a height of 185 feet above mean tide, which was 20 or 25 feet below the level of the flood at Hartford; and the terrace topping the divide has a height of about 20 feet.



(3.) *The slope of the flood-level was widely different above and below Farmington.*—The slope of the terrace (or of flood-level) for the first 33 miles, that is, from Northampton to Simsbury (*Sb* on plate 5) was only 6 *inches* a mile; and for the first 44 miles, or to Farmington, about 7 *inches*; while southward, from Farmington to a point 2 miles north of Cheshire, where the high land of Cheshire begins, it was about 5 *feet* a mile; from the latter place to the Mt. Carmel gap, about the same; and from Mt. Carmel village to New Haven Bay, 10 *feet* a mile. A reason for this change in slope at Farmington exists in the fact that the flooded Farmington River here entered the valley from an extensive region to the northwest, and the Pequabuck added waters from the west; the two draining a high portion of western New England about 200 square miles in area. The flood consequently received its greatest accessions at this point; and the waters were so rapidly supplied that the slope northward was diminished and that southward increased. On the *west* side of the valley to the north of Farmington station, the upper terrace is well displayed, and especially along by Simsbury and for a mile and more to the north, where it is 130 feet above low water in the river and quite wide. But on the *east* side of the valley the terrace above Farmington is for the most small, no large stream, capable of affording transported material, flowing from that direction because of the nearness of the trap range.

Further, the terrace deposits are greatly coarser south of the Farmington River entrance than to the north of it. To the north they are chiefly of sand with fine or coarsish gravel above; but near the Farmington station and south of it through Southington and beyond, the deposits are remarkable for their coarseness, as above stated.

(4.) *A great change in the old hydraulic conditions.*—Before the era of the flood the drainage south of Northampton, supposing the land to have had nearly its modern slopes, was as follows : for a dozen miles *northward ;* then *eastward*, in Westfield river; for the next three miles, the first half *northward* and the second *southward ;* then for 17 miles *northward*, by the Farmington River and the Pequabuck; finally, for the rest of the distance to New Haven, 25 miles, *southward*, excepting a break of two miles between the Quinnipiac and the head of Mill River. But, in the era of the flood, this whole uneven region of many slopes, was under one continuously sloping water-plane, having a fall, if reckoned on the basis of the present slope of the land, of 290 feet in 77 miles. The northward-flowing streams and the streams at equilibrium as to erosion and deposition, or at "base level," if any there were, were merged with the southward flowing streams into one great southward hurrying flood, the depth exceeding 120 feet at maximum height and 40 feet where shallowest. It is an example, though on an extreme scale, of the kind of change over a region which a modern flood may produce in hydraulic conditions and in the activity of fluvial forces.

The flood produced other effects over the New Haven region south of the Mt. Carmel gap, which are of much geological interest. These will make the subject of another article.

A few words only are here added as to the bearing of the facts reviewed on the question with regard to *the slope of the land in the era of the flood.*

In my paper on "flood of the Connecticut River valley," in volume xxiii of this Journal (1882), it is apparently proved that the southward slope of the land was much less during the flood than now—the calculated mean diminution from the Sound to Springfield being one foot a mile, and from Springfield to Haverhill 2½ feet a mile. Hence we should expect to find evidence of some corresponding difference of slope to the westward of the Connecticut over the Farmington valley. But it follows from the facts presented that the diminution in slope between Farmington and Northampton *could not have been* 1 *foot a mile without producing a current northward*, and so making Northampton the place of discharge instead of outflow; for it would have given a mean slope in that direction of 5 to 6 inches a mile. Mr. Diller, in his paper on the Westfield region, mentions as evidence of a *southward* flow from Northampton that the terrace material over the Hampton "divide" diminishes in coarseness southward, and that it contains a great abundance of fragments or pebbles of trap which had their only source to the northward in the northwest angle of Mount Tom. Moreover, since the fall from Northampton to New Haven at maximum flood was in any case over 200 feet, it is impossible, without a most improbable inflow, that the waters should have been so piled up at Farmington as to flow in opposite directions. We have to conclude, therefore, that the diminution in slope southward must have been less than 7 inches a mile. No clay deposits are known to occur in the Farmington terrace deposits, and no other evidence of lacustrine conditions.

South of Farmington the coarse deposits may have been made with the slope diminished a foot or more.

In the Meriden valley, where the terrace formation consists mainly of sand, the present pitch of the terrace-level is much too great for such depositions. From Hanover Pond to North Haven the mean slope, according to Table II, is 4½ feet a mile; and about 4 feet, from the same point to Fair Haven.

[From the American Journal of Science, Vol. XXVI, Nov., 1883, and Vol. XXVII, February, 1884.]

PHENOMENA OF THE GLACIAL AND CHAMPLAIN PERIODS ABOUT THE MOUTH OF THE CONNECTICUT VALLEY, IN THE NEW HAVEN REGION.

BY

JAMES D. DANA.

ART. XXXIX.—*Phenomena of the Glacial and Champlain periods about the mouth of the Connecticut valley—that is, in the New Haven region;* by JAMES D. DANA.

THE Glacial phenomena over the New Haven region have many points of special interest, an important part of which arise from the fact that the ice of northern New England which had moved down the Connecticut valley or trough, here left the mainland for a passage through Long Island Sound. The subject includes therefore a discussion of the relations between the part of the glacier to the north and that over the Sound and beyond, and suggests questions as to—

(1) The thickness of the glacier at this southern end of the trough, and the pitch along the trough.

(2) The fact or not of two directions of movement in the ice —a *lower* or *trough stream* south-southwestward, and an *upper stream* southeastward; and, if two, as to their being simultaneous or not.

(3) Any mixing of drift materials from the two streams.

(4) The direction of movement after escaping from the confines of the Connecticut trough and entering the east-and-west trough of the Sound.

(5) Any effects in the New Haven region consequent on a change of direction in the glacier-movement.

The phenomena also of the early Champlain period, when the floods from the dissolving glacier were pouring down the valley and made use of New Haven Bay for the outlet of part of the waters—repeating the drainage conditions that existed long before in Triassic time—have a wide bearing, especially those connected with—

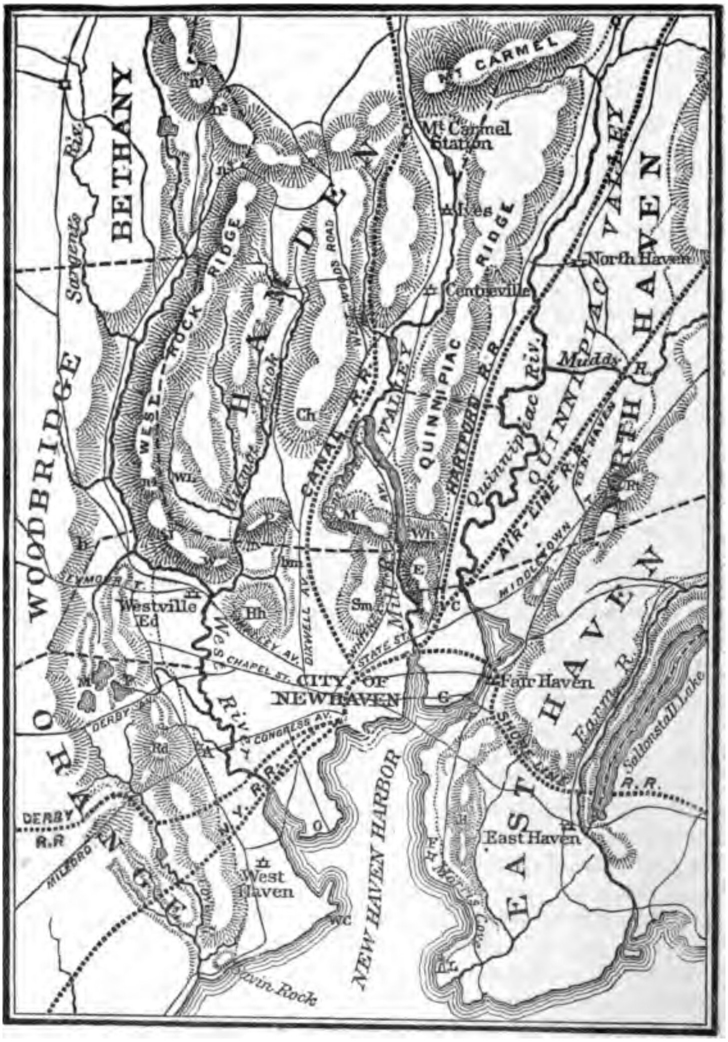
(1) The structure and seaward slope of the New Haven terrace-formation, or the deposits of stratified drift which underlie the broad New Haven plain.

(2) The occurrence, over the flood-made fluvial deposits of the plain, of more than forty isolated basin-shaped cavities called "kettle-holes."

(3) The existence also of two broad north-and-south depressions in the plain, each over a mile long, which look like deserted river channels.

(4) The apparent connection of these depressions and the "kettle-holes" with a former system of drainage, characteristic of the Glacial era.

(5) The existence of a terrace on the bay, testifying to the sea-level during the era of the flood.



MAP OF THE NEW HAVEN REGION. Scale 4-10ths inch = 1 MILE.

Explanations.—A, Allingtown. B, Beacon Hill. Bh. Beaver Hills. Ch, Cherry Hill. E, East Rock range, consisting of East Rock to the north, next south Indian Head, and further south Snake Rock. Ed, Edgewood. F, Fort Hale. *F*, Ferry Point, or Red Rock, on the Quinnipiac. G, Chapel Street. J, Judges Cave, on the West Rock ridge. L, Old Light House. M, Mill Rock. M P, Maltby Park. O, Oyster Point. P, Pine Rock. Rd, Round Hill. Rt, Rabbit or Peter's Rock. Sm, Sachem's ridge. T, Turnpike: also Tomlinson's bridge, across the head of New Haven Bay. V, Whitneyville. W, West Rock, the south end of West Rock ridge. W C, West Cape, or West Haven Point. Wh, Whitney Peak. W L, Wintergreen Lake. *b*, 1200 ton bowlder in Woodbridge. *bm*, Beaver Pond Meadows. *n*1, *n*2, *n*3, *n*4, different notches in the West Rock ridge; *n*1, *n*2, the upper and lower Bethany Notches; *n*3, the Hamden Notch; *n*4, the Wintergreen Notch.

Some of these points were discussed by me in 1870, in a paper on "the Geology of the New Haven Region," published by the Connecticut Academy of Sciences in the second volume of its Transactions. But since that time many new facts have come to light, sustaining some of the conclusions then presented and requiring modifications of others, besides affording fuller illustrations of all the various characteristics of the plain. Further, in the interval which has elapsed, a topographical survey and chart of the region have been made under the auspices of the Coast Survey and the special superintendence of Mr. R. M. Bache, assistant U. S. Coast Survey, laying down the features of the surface with great accuracy, and indicating the level over the whole area by 20-foot contour lines. In my endeavor to secure such a survey, I had especially in view its use as a basis for geological investigations and reports; and it fulfills well the purpose. Moreover, it has brought to view new facts, and given greater precision to our knowledge of topographical details. A review of the subject with the aid of all the additional light obtained is therefore needed.

On the preceding map, the *New Haven region* comprises all of the area south of the trap-and-sandstone range of Mt. Carmel, and east of the range of hills of metamorphic schists which make its western border through the towns of Orange, Woodbridge and Bethany.

The *western* border region has a rather abrupt eastern front, and rises in height from 100 feet above mean-tide level on the south to 650 feet on the north. This western border was the western margin of the deep Connecticut trough and estuary of Triassico-Jurassic time, all the rocks of the region eastward of it being trap and sandstone of that era; and it was the occasion of important results also in the Glacial and Champlain periods. South of Westville it is a *double* ridge—that of a broken-backed anticlinal—a shallow valley of ledges and marshes (one-fourth to three-fourths of a mile wide) separating an eastern and a western range of hills.*

The outline of the flood-made terrace-formation is indicated on the map by a dotted line, at the base of the hills. As is seen, the three principal valleys and former flood-ways of the region—West River, Mill River and the Quinnipiac—open southward into the broad New Haven plain. The Quinnipiac valley is separated from that of Mill River by the Quinnipiac ridge, made of sandstone hills 100 to 250 feet in height, with East Rock ridge, 362 feet in greatest height, at its south end; and Mill River valley from that of West River, by the "West Rock Ridge" of trap (dolerite) 400 to 600 feet in height, together with the various sandstone hills that lie to the east of it.

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*The valley is called, from the portion of it at M on the map, Maltby Park valley. See also the map on page 358.

On the eastern margin of the region the hills are of trap and sandstone; the largest of the trap ridges constitutes the western border of Lake Saltonstall.

After this introduction, I will take up, first, the phenomena of the Glacial period, discussing the points in the following order:

1. The fact of a southward (S. by W.) movement in the *lower* ice of the glacier along the Connecticut valley, and the angle of slope of the surface of the ice in the direction of the valley.
2. The fact of a *southeastward* movement (S.S.E. to S.E.) in the *upper* ice.
3. The correlations of the two movements as to time and as to drift depositions.
4. The direction of movement over Long Island Sound.
5. The drift deposits, and the probable effects of the wrenching attending the change of direction which they exhibit.

I. GLACIAL PHENOMENA.

1. *The fact of a Connecticut valley movement and the probable surface-slope of the ice in the direction of the valley.*

a. The fact of the valley movement.—The fact of the valley movement I pointed out in 1871,* basing the conclusions on (1) observations in Massachusetts, by Professor Edward Hitchcock, published in the Massachusetts Geological Report (1841), (2) observations in Vermont, from the Vermont Geological Report (1861), made chiefly by Professor C. H. Hitchcock, (3) a map of New Hampshire by the latter, giving the directions of glacial scratches, published in advance of the final Report on the Geology of that State, and (4) on my own investigations. The facts supplied by Professor Edward Hitchcock, the earliest careful investigator of the subject on the continent, were sufficient alone to establish the truth announced; and he recognized it, but made the ice mainly that of icebergs. The same conclusion is presented in the Vermont Report. But in the New Hampshire Report, published in 1878, the movement is made by Professor C. H. Hitchcock a *glacier* movement.

The fact *is proved by the glacial scratches*. All observations from New Haven northward to Windsor in Vermont, 140 miles, give, with rare exceptions, courses between S. and S. 20° W. In the upper part of the valley, north of Windsor to Wells River, 60 miles, both southward and southeastward directions occur.

It *is proved also by the drift transportation*. Of the drift material in the New Haven region, more than 99 per cent, including bowlders innumerable, from one ton to 1200 tons in weight, were derived from the trap and sandstone *of the valley*, that is, were taken up in the valley and transported along the valley. The proof is hence positive that the transporting agent moved down the valley, gathering the stones and earth by the way, and, sooner or later, depositing also by the way. The mean course of the Connecticut valley in Connecticut, from the Massachusetts boundary to New Haven bay, is S. 17° W., and this is about the mean course of the scratches and drift.

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* This Journal, II, li, 233.

b. Directions of the bottom movement over the New Haven region; the large amount of WESTING *along the western border and beyond over Orange and Milford.*

The glacial scratches in the eastern part of the New Haven region, over East Haven, about the various opened quarries, indicate a movement in the direction S. 13° W. The usual trend of the sandstone ridges of East Haven is about the same, showing that they owe their forms to glacier abrasion. Sachem's Ridge (Sm on the map), made into a ridge by the ploughing glacier,* because of the protecting Mill Rock to the north, has a trend of S. 11½° W. In Hamden, farther north, the "Quinnipiac Ridge" (similarly carved out by the glacier because under the lee of Mt. Carmel) has the mean course S. 16° W. The valleys and sandstone ridges west of this ridge have nearly the course of the West Rock ridge to the west of them, or S. 26° W.† Along the western border of the New Haven region, in Orange, the course at the many scratched ledges is S. 26°–38° W., and mostly S. 33° W. But it varies over Maltby Park, (M on map) to S. 45° W. and S. 56° W. owing to local conditions.

The large amount of westing on the western border was pointed out in my paper on the New Haven region of 1870; but I have now the additional fact that the course S. 33° W. occurs to the westward of this border over Orange and Milford, for half a dozen miles from the New Haven region, or nearly to the Housatonic and Naugatuck valleys, showing that the southwestward movement had a wide westward extension. The fact points, I suppose, only to near uniformity of direction in the low and broad valleys and ridges of the surface; and proves that the topography, notwithstanding the fact that the rocks are fragile slates, was of pre-Glacial origin.‡

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* Ploughing deeply over the soft sandstone formation, but feebly abrading over the trap.

† An exception as to westing occurs two miles north of Westville in the narrow West River valley, where the course of grooving over the slate rocks is South; an exceptional course evidently due to the form of the surface at the place.

‡ Many variations in the directions of glacial scratches are due simply to the varying slopes in the land-surface underneath. The variations usually found about a knoll are an example on a small scale. Only when the slopes of the land-surface and upper glacier-surface coincide in compass-course, will the scratches have the direction of the glacier-flow. If these surfaces are oblique to one an-

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The positions of the great bowlders and of the accumulations of drift correspond as to the amount of westing with the courses of the scratches.

The larger bowlders of trap and sandstone lie in the *western* half of the New Haven region. Further, they are gathered in great numbers, together with thick deposits of till, along the hilly *western border*, and especially the *eastern declivity of the high border*—as if moraine-like in origin. But some bowlders of large size occur on the top and eastern declivity of the West Rock ridge, which is one to two miles east of that western border, and a few are found farther east.

One of the largest of the trap bowlders, called the Judges' Cave, lies on the top of the West Rock ridge (at J, a mile north of Westville), at a height of about 365 feet, where it was probably stranded because 25 feet too low in the ice to clear the top of the ridge. It is now in a few large pieces, probably through the rending action of growing trees, but weighed when entire at least 1000 tons. Just a mile west of the "Judges' Cave" on the Woodbridge declivity, lies a still larger bowlder of trap and entire, its extreme length 42 feet, and estimated weight 1200 tons. The spot where it rests is about 360 feet above the sea-level, and 20 feet below the summit beyond it. But a few rods south lies another of 100 tons, and a few hundred yards to the north there is a group of five great trap bowlders, the largest about 200 tons in weight, that were similarly stranded—a most impressive assemblage. Three-fourths of a mile north *on the same declivity* lies another bowlder of 500 tons. Many more of great size—500 tons to 10 (equivalent to 6000 cubic feet to 120), occur both north and south along this border. Further, very few trap bowlders of large size passed its summit. One, measuring 13×9×5 feet, lies a mile west of it in southern Woodbridge; a group of others, the largest 17×15×5 feet, at the same distance nearly, in northern Woodbridge; and one of 8×5×7 feet in northern Orange, west of Maltby Park. Smaller trap bowlders or stones however, with others of sandstone are widely distributed for three to six miles in that direction; on the south they reach beyond Milford.*

The *course of travel* of some of these great bowlders can be made out quite closely. They were derived either from the

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other, the scratches at bottom will have an intermediate direction, which will be determined by (1) the angles of the two slopes, (2) the angle between the dip-directions, and (3) the thickness of the overlying glacier. (The velocity was too small to be included.) Hence, some variations in the direction of scratches in a given region are to be expected rather than perfect uniformity, even where there are no defined troughs or valleys.

* A trap bowlder, measuring 15 × 8 × 6 feet, lies near the Housatonic River above the railroad crossing; but it is probably from a dike that intersects the metamorphic rocks from southern Woodbridge to the mouth of the Housatonic.

West Rock Ridge or from some part of the Mount Tom range* to the north; for the more eastern trap ridges are too far east. They are, for the most part, alike in consisting of *fine-grained much-rifted* trap, the variety that occurs only as the *outside* of the ejected trap-masses where the melted rock was *rapidly cooled* against the sandstone or air. Hence they probably came from the *top* of the ridges, for the sloping eastern side is now usually under sandstone to within 100 feet (in height) of the top, and the western is that of the bold columnar front.

The trap ridges projected upward into the ice abruptly, several hundred feet—the Mt. Tom ridge (or that from Meriden to Mt. Tom in Massachusetts) probably 600 to 900 feet; a most favorable condition for the successful rending and grasping work of the glacier. The Mt. Tom ridge is 996 feet high (Guyot) in South Mountain, Meriden, 985 feet in Talcott Mountain, west of Hartford, and 1214 feet in Mt. Tom. Some of the fallen masses at the base of its bluffs near Meriden are as large as the largest of the bowlders. Moreover, the trap (doleryte) of this western trap range in Connecticut is mostly a hard, durable rock, while that of the more eastern trap range is generally a hydrous or chloritic kind, very decomposable, and having usually only small chips as its fallen masses. This is one reason why large trap bowlders are rare to the eastward.

The "Judges' Cave" certainly came from the Mt. Tom ridge, —either the main ridge or those subordinate to it, and either from the vicinity of Meriden (16 miles distant), or some point farther north. The trap beneath it is very unlike that of the bowlder. If from the Mt. Tom ridge, the direction of travel was between S. 22° W. and S. 12° W.—the latter if from the northern half of the ridge.

The 1200-ton bowlder, near the top of the Woodbridge border, was probably from nearly the same source, the rock being closely the same; and its course was therefore between S. 24° W. and S. 16° W. If the former, it had passed over the West Rock ridge, at a height of at least 500 feet; if the latter, its course was west of this ridge.

Supposing, in the case of each of these bowlders, the height whence taken to have been 900 feet, the former had sunk in the ice before landing 550 feet, and the latter 540 feet. A 500-ton bowlder that must have had the same course with the "Judges' Cave" and may have been its near companion in the ice, continued on *over the West Rock ridge* and now lies S. 21° W. of it, a mile and a half farther south (on the grounds of Mr. Donald G. Mitchell). It is about 120 feet above the sea-level—which indicates a sinking in the ice, after passing the

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* The Mount Tom range of trap extends north from Meriden to Mt. Tom in Massachusetts. See map, Plate v, in volume xxiv, of this Journal, June, 1883.

West Rock ridge, of nearly 300 feet, or half the whole amount it experienced before it landed. Two other large bowlders lie near it. It is possible that these, and others of the bowlders, reached terra firma at the final melting, or through crevasses, in which case part of the sinking may have taken place abruptly.

The distribution of bowlders and till along the western border has been stated above to be somewhat moraine-like. But it is largely a consequence of the fact that these hill-slopes, 300 to 400 feet in height above the plain fronting them, faced obliquely the advancing ice, the trend of the border being north and south, and the flow of the ice S. 12°–35° W. Consequently, as above illustrated, the stones and earth that were not high enough in the glacier to pass the summit, were dragged out or dropped. There was also diminished movement and therefore long detention of the ice-conditions against the declivity, and this favored deposition.

Probable slope of the upper surface of the ice down the valley. To understand the conditions at the south end of the great valley it is necessary here to consider the question as to the slope of the ice in the direction of the Connecticut valley on which the southward movement was more or less dependent.

Wells River (a little north of the latitude of the White Mountains), is distant from New Haven about 200 miles, and from the south shore of Long Island, the supposed southern limit of the glacier, 240 miles. The height of the ice-surface about the White Mountains above the sea-level, according to the best observations, including those by Professor C. H. Hitchcock, was at least 6,000 feet and probably 6,500 feet. Assuming the height to have been 6,000 feet and this level to have extended west-by-north (the probable direction of contour lines on the glacier) over the Wells River region, the slope of the ice along the 240 miles would have been about 0·17′, equal to 4¾ feet in 1,000, or 25 feet per mile. With the height 6,500 the slope would have been 5 feet in 1,000. Either angle of slope is very small. In the Alps the lowest mean-slopes are 2½° to 3°, or 4½ to 5¼ feet per 100, a rate ten times greater than the above; but the thickness of the ice there is not over 500 feet. In Greenland, where the conditions were much like those of glaciated North America, the slope observed by Jensen over the Frederickshaab glacier* was 0·49′, or about 75 feet per mile; and that measured by Helland on the glacier in the vicinity of Jakobshavn, 0·26′, or about 45 feet per mile. 45 feet to the mile would make the height of the ice-surface at Wells River over 10,000 feet.†

From such facts it would appear to be a safe conclusion that the height of the ice-surface above the sea-level at Wells River and the White Mountains was *at least* 6,000 feet. On this assumption, and supposing the slope of a line on the surface in the direction of the valley equable, and the height at the southern termination on Long Island, 100 feet, the height over the region of Windsor and Mt. Ascutney, in Vermont, would have been about 4,500 feet, and over the New Haven region very nearly 1,000 feet.

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* Meddelelser om Grönland 1879, and this Journal, III, xxiii, 363, 1882.

† Even smaller angles of slope are stated to be sufficient to cause motion in

It is still a question whether the height of the ice-surface to the northward was due solely to the accumulation of ice and not partly to an increase in the southward slope of the land. Yet, since even an increase in elevation of 500 feet would make little difference in the result, it follows, if the above conclusion as to the amount of slope required for movement in the valley is admitted, that

(1) For *movement down the valley the ice should have had nearly or quite its maximum thickness;* that is, the maximum thickness of the great glacier over that region. Further, that

(2) *Its flow could not have continued after melting had far advanced;* and further, that

(3) *Movement in the valley over lower New England by local glaciers after the disappearance of the general glacier is improbable;* the supposed local glaciers (as the scratches likewise show) were merged in the one great glacier, *and acted locally only through its aid.* Supposing the great glacier to have melted away so as to have reduced the ice over the valley to just the limits of the Connecticut valley, which is nowhere over 1,500 feet deep and generally less than 1,000, it is not at all probable that with this slope (the mean for the valley 3·3 feet a mile, this Journal, xxiii, 190, 1882) the ice could have overcome the various resistances to motion.

2. *The fact of a southeastward movement in the upper ice of the Glacier.*

The evidence as to a southeastward movement in the upper ice is afforded by *glacier scratches outside* of the valley, and by *transported bowlders within it as well as outside.*

a. Glacial scratches over the high plateaus of western and northwestern Connecticut, 800 to 1,500 feet in elevation, have directions between S. 12° E. and S. 45° E.

Greenland, but better measurements and knowledge of conditions are needed before any confident conclusion can be drawn.

In my paper of 1873 (this Journal, III, v, 108), I assume a slope of at least 10 feet a mile, and this gave a height for the glacier of 13,000 feet in the region of the supposed icy plateau on the Canada water-shed. For a reason stated beyond, the surface along the line crossing the St. Lawrence valley may have been level, and the slope confined to the ice above and below it; and that above may have been only just enough to keep the St. Lawrence valley full to the required level.

According to my observations in Connecticut, the direction in eastern Huntington is S. 14°–25° E., and near Lane's Mine in Monroe, S. 12°–13° E., places within 12 miles of the New Haven region; in the towns of Norfolk, Preston and Kent, farther west, S. 18°–20° E.; of Warren, S. 30° E.; of Newtown, S. 32° E., and 2 miles farther west, S. 41° E.; of Sharon, S. 33°–36° E.; of Cornwall, S. 33°–36° E.; and on Mt. Washington and its highest summit, Mt. Everett, in southwestern Massachusetts (the latter, 2,634 feet high), S. 18°–29° E. The direction in Goshen, according to Mr. H. Norton is S. 23° E. and S. 38° E.; in Norfolk, according to Mather, S. 20°–25° E.; and on Mt. Tom, in southwestern Litchfield, according to E. Hitchcock, S. 17°–22° E. Other facts of similar import from eastern New York, Massachusetts, Vermont and New Hampshire, are given in my former paper. The following White Mountain observations, from the New Hampshire Report by Professor C. H. Hitchcock (vol. iii, pp. 177–195), are of later publication.

Mt. Adams, W. side, height 5,500 feet	S. 58° E.
Between Adams and Jefferson, near gap (4,939 ft.)	S. 33° E.
Top of Mt. Washington (6,293 ft.), smoothing and faint markings (at 5,800–6,000 feet, transported stones, p. 204), but striæ obscure	S. 43° E.
200 feet above Lake of the Clouds	S. 30° E.
Lake of the Clouds (5,000 ft.), the intersecting directions	S. 22° E. S. 52° E.
Between Mt. Pleasant and Mt. Franklin (4,400 ft.)	S. 30° E.
Between Mt. Pleasant and Mt. Clinton (4,050 ft.)	S. 30° E.
Near top of Mt. Clinton (4,320 ft.), N. side	S. 47°–52° E.
Mt. Clinton, S. peak	S. 50° E.
South end of Mt. Webster	S. 37° E.
Top of Mt. Webster (4,000 ft.)	S. 30° E.
Top of Mt. Moosilauke (4,811 ft.)	S. 22° E.

The abrasion observations thus far made appear to show that the *mean direction of glacier flow* in western Connecticut and Massachusetts was somewhere between S. 12° E. and S. 38° E., and probably between S. 12° E. and S. 25° E.

b. The evidence from bowlders outside of the Connecticut valley is of the same import.

Percival states that transportation over Litchfield was S.S.E., as indicated by the distribution of limestone blocks from Canaan—which means about S. 20°–25° E. A few of these Canaan limestone bowlders I have found lying now in Orange, within four miles of the New Haven region, indicating transportation for 48 to 50 miles in the direction S. 16° E. They are easily recognized by the tremolite and canaanite (massive white pyroxene) they contain. Bowlders of quartzyte, from the same region, or from Berkshire, just north, are widely distributed. Bowlders of porphyritic gneiss from the northwest are very numerous over Orange and Woodbridge.* It is not necessary to multiply facts of this kind; for it is a matter of common observation over New England that the chief part of the drift came from the northwestward.

c. Bowlders within the area of the wide Connecticut valley prove that the southeastward movement or ice-stream extended over the valley. Those of the unmistakable porphyritic gneiss of the Naugatuck valley, which are scattered so widely over Woodbridge and Orange, occur also in the New Haven region; and one, now three miles east of the western limit of the region is over 20 cubic feet in size. Masses of ordinary gneiss, from the same general source, are numerous for two miles east of the western border, and among them are some of 100 cubic feet and larger; and smaller ones down to a foot in diameter are of occasional occurrence for a distance of at least twelve miles eastward. Quartzyte bowlders, derived, in all probability, from the Canaan or Berkshire region, are more numerous than those of gneiss, evidently because of their greater durability; they are scattered widely, and I have found some, probably from the same source, 15 miles northeast of the city of New Haven.

Similar facts have been observed through other parts of the Connecticut valley. Professor E. Hitchcock states, in his Massachusetts Report (1841, p. 381), that the bowlders of syenyte and granite from the west side of the Connecticut in Massachusetts are found in great numbers on the east slope of the Mt. Tom range, all the way from Mt. Tom to Hartford. To this I add that I have found a syenyte bowlder from the same source 10 miles south of Hartford, and 15 from the western limit of the old Connecticut valley. He says also (p. 605), that bowlders of quartz containing manganese and iron ores in peculiar concretionary forms, derived from Conway *west* of the valley, are abundant about Amherst, southeast of Conway near the *east* border of the valley, and Professor B. K. Emerson, of Amherst, informs me that they occur farther east in Pelham.

Up the valley to Windsor, Vermont, the same courses have been reported by Professor C. H. Hitchcock, who says, in his New Hampshire Report (iii, 263, 1878), that bowlders from Mt. Ascutney (which stands on the west border of the valley and has a height of 3,200 feet), are distributed southward along the valley to Bernardston, over 60 miles, *but also southeastward* across the valley; one, 20 feet long, 27 miles, was carried

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* The crystals of feldspar in this porphyritic gneiss are generally 2 inches long and ¾ inch wide, making the rock easy to identify. It forms part of a band of gneiss to the westward of, and 10 to 20 miles from, New Haven, ranging in a N.N.W. direction from Bridgeport to Prospect, places bearing S. 45° W. and N. 12° W. from New Haven.

S. 10° E., into Surry; another 5 feet long, 35 miles, S. 8° E. into Keene; others, 42 miles, S. 20° E., to the west base of Monadnock; along with which large bowlders, occur many others of smaller size.

It is thus evident that a glacial movement in a direction crossing the valley south-southeastward is as well established as that in the direction of the valley. North of Windsor evidence of both movements occurs, as already stated; southeastward scratches are most common.

3. *Correlations of the two movements as to time and drift-depositions.*

a. The valley movement continued until the general glacier-flow in the region ceased. For the scratches in the direction of the valley are the last that were then made. They are not only scratches, but over the sandstone often deep ploughings; not of occasional occurrence, but universal, every fresh removal of soil from the rock bringing them to light, and showing in Connecticut, as far as observed, no marks of any later transverse movement.

b. The valley movement was cotemporaneous throughout with the general glacier-flow. This follows from the statement on page 349 as to the thickness of the ice and the angle of slope required for a valley movement. It is indeed a necessary consequence of the fact that thickening the ice over a valley to maximum thickness would increasingly facilitate the flow in its direction, notwithstanding any transverse motion in the general ice-mass; and a thinning that would finally leave it a local glacier would enfeeble its motion or stop it altogether.

Consequently valley-movements, with exceptions in a mountain region, were not those characterizing the beginning or end of the Glacial era, but the movements that prevailed through its height. The two went on together, an *upper* general flow over a *lower* valley flow.

c. But *it may be questioned whether the upper flow kept its course unchanged quite across the great valley of the Connecticut in the States of Massachusetts and Connecticut.*

A small narrow valley, especially if steep or gorge-like, would have no valley-flow of ice, owing to friction; and the glacier would readily pass it, impeded only, if at all, by the resistance from shearing. But where the valley was larger, and had its valley flow, the case is different; yet facts that have been collected prove that this resistance was overcome in multitudes of cases over the country. And it was so in the case of the Connecticut valley in Vermont and Massachusetts, the facts above cited as to transported bowlders about the region of Amherst and Massachusetts being evidence. About

Ascutney there appears to have been some southward deflection of the *upper* or *southeastward* stream by the valley flow, for the direction of transport across is in part only 8° east of south; yet the differences of direction observed (p. 351) may have been due to the height on Ascutney from which the bowlders were taken, whether within the range of the lower current, or near the limit of the two, or far above it. About Amherst the evidence from bowlders proves clearly that the upper ice-stream continued quite across the valley. In central and southern Connecticut, the valley has a breadth of 25 miles; and positive proof that the upper current continued across has not yet been found. The distribution of bowlders indicate a flow half way across, and probably farther; but whether the upper ice did not finally in the eastern half lose its own motion and take that of the lower for the remainder of the breadth of the lower stream is yet to be ascertained. Such an event could not have happened unless the valley-flow succeeded, by its rate of discharge, in taking the southeastward slope of the overlying ice out of it, so that the only surface slope along this portion was in the direction of the valley; and were this done, the valley movement would have necessarily become the only one. Even if this were a fact, the slope of the ice-surface *east* of the eastern border of the Connecticut trough would have been southeastward, and so also the course of movement.

d. Great deflections in the courses of the transported bowlders within the valley took place on account of their sinking from the upper or general current into the lower or valley stream. In this way, as happens in the ocean, the lower current became the transporter and distributer of material derived from the upper. It was supplied with stones from the *north*westward and carried them *south*westward.

This fact is abundantly and strikingly illustrated in the distribution of the bowlders of gneiss. In the New Haven region they are far the most numerous, and of largest size, along the *eastern* slope of the West Rock ridge. The map shows that this ridge curves eastward at its southern extremity, making thereby a large deep corral of sickle-like outline facing almost directly the valley ice-movement, whose direction there was S. 16°-26° W. These bowlders of gneiss are most abundant over this portion of the declivity, south of Wintergreen Lake. A few hundred yards south of the lake, one of the bowlders, now in three pieces, has a length of 12 feet.

These bowlders, derived from the high land of northwestern Connecticut, must, beyond question, have passed the summit of the West Rock ridge—where between 400 and 650 feet in height—while in the upper stream of the glacier; for in no other way could they have got to the *east* side of the ridge;

and it is also beyond question that they finally got into the valley current, and were drifted back into the well-arranged corral. Some are now on the summit of the ridge; one of several cubic feet is near the "Judges' Cave;" but the larger part are a third way down the eastern slope and below this level. The gneiss bowlders are mingled with those of trap and sandstone; and nothing shows difference in time of deposition.

This kind of evidence is repeated again along the Mt. Tom ridge. Professor E. Hitchcock states in his Massachusetts Geological Report (p. 381) that bowlders of syenyte and granite, taken from the syenyte band west of the Connecticut in that State, are found in great numbers on the *east* slope of the Mt. Tom range *all the way from Mt. Tom to Hartford* Eight miles farther south, in the village of New Britain (as made known by Mr. James Shepard of that place), a bowlder of zoisite and radiated hornblende (chiefly the former), measuring about 2×2×3 feet, was turned out in grading, which must have come from a locality *west* of the Connecticut valley, in Goshen, Williamsburg or Conway, Mass., Professor Emerson informing me that this region affords just such a zoisite rock, and especially "the first row of high hills as you go up from the Connecticut valley." (Letter of June 16, 1883.) Still farther south (20 miles S. of Hartford) and just *east of a more eastern* trap ridge (6 miles farther east), extending from south of Hartford to Saltonstall Lake, I found, near the Air-Line Railroad, a syenyte bowlder 10 cubic feet in contents, which came from the syenyte band of Hatfield and Whately, Mass. (Emerson), west of the valley;* and near it lies another twice larger, of similar general aspect, but not so certainly identifiable.

Such facts prove that the phenomenon, although so remarkable, was general along the valley. They are instructive also with reference to the distance eastward to which the upper ice-stream extended over the southern part of the Connecticut valley region, though leaving the limit doubtful. They are good evidence that the two currents were moving at the same time.

4. *The direction over Long Island Sound.*

For twenty miles to the eastward and westward of New Haven bay the Sound has a mean width of 16 miles. Yet the greatest depth opposite New Haven bay is at present only 140 feet. Adding the height of the adjoining hills on its sides, the southern side of the trough has a height of 300 to 400 feet and the northern, of more than twice this amount.

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*I submitted a fragment of the bowlder to Professor Emerson, of Amherst, and he writes that it is from the "syenite" band of Hatfield and Whately (Hitchcock's geological map), it agreeing precisely with it, containing much triclinic feldspar and small square crystals of orthite."

Since the Connecticut valley trough is not continued over the bottom of Long Island Sound, or through Long Island, the valley ice, as it moved out over the area of the Sound, left behind it those confining limits which had determined its southward course; and it is a question of interest whether it found new confining limits, or not, in the sides of the Sound trough.

The trend of the Sound is N. 75° E. Now this trend is transverse to the course of the *upper* or southeastward ice-stream of the glacier, the direction of this current having been, as above shown, S. 15°–25° E.

The mean direction was between these limits quite to the borders of the Sound; for on the Sound, 8 miles east of New Haven, near Stoney Creek, glacial scratches, covering large surfaces of gneiss and granite, have the direction S. 20° to 24° E.; others, 10 to 12 miles west of New Haven, in Stratford (near the N. Y. & N. H. railroad), S. 21° to 32° E.; and 18 miles west, near Bridgeport, S. 13° to 17° E.

Further, the bowlders of Long Island show that this was approximately the direction of flow over the Sound. Trap and sandstone bowlders were carried in great quantities from Connecticut to the island, and the most abundant deposits are situated on the parts lying S. 10°–20° E. from the New Haven region where alone the Triassic borders the Sound. On the north shore of the island, between Baiting Hollow and Northville, a region bearing S. 10° E. from New Haven, the bowlders of trap are very numerous; and the sandstone fragments at one place on the shore hills are in so great quantities that they seemed at first to indicate the existence near by of an outcrop of the Triassic.

Mather mentions the same fact in his New York Geological Report, remarking, on page 170, that from Roanoke Point for three or four miles east (points between Baiting Hollow and Northville) "a large proportion of the bowlders and pebbles are of red sandstone and trap rocks, like those of New Haven and that vicinity. In some places these rocks form one-third of the mass of bowlders, blocks and pebbles." He also states (p. 171) that a mile west of Wading River (4 miles west of Baiting Hollow) "a block of fine-grained limestone containing serpentine was found; it was precisely similar to the New Haven verd antique marble." It was probably from the Milford verd antique quarry, six miles southwest of the New Haven quarry, where the rock is more largely limestone than at the latter; in which case the mean direction of travel was S. 25° E.; if from the New Haven quarry, it was S. 13° E.

On one of the hills in the interior of the island, southwest of Riverhead, near Osborn or Bald Hill, bearing S. 15° E. from

New Haven, lie several large bowlders of trap, and one of red sandstone, along with others of gneiss. One of the trap bowlders contains over 200 cubic feet. Farther east, trap and sandstone bowlders are in rapidly decreasing numbers; and the same is true of the region to the westward.*

If then, as we have shown, the flow of the mass of the great glacier was at right angles to the Sound valley, it would have tended to move the ice of the Sound against and over Long Island, and not at all in the direction of the Sound, N. 75° E. To have had an eastward movement in the direction of the Sound the surface of the Sound-ice should have had a rising slope westward, and this is opposed by the facts already stated.† It is certain, therefore, that the view that the Sound valley was excavated by the glacier is not tenable. Further, the *lower* ice-stream, or that of the Connecticut valley, struck the ice of the Sound in the direction S. 13°–25° W., which would have helped a westward flow rather than an eastward.

All the facts thus point to the conclusion that the great glacier passed, with essentialy unchanged course as far as the upper ice is concerned, from Connecticut across the Sound and the island beyond. At the same time, the existence, though sparingly, of small masses of trap on Long Island for a few miles west of the meridian of New Haven, appears to show that this valley-stream moved south-southwestward not only over the towns next west of the New Haven region but at times also nearly across the Sound before losing wholly its own direction.

5. *Effects probably consequent on the change of course in the lower, or valley, ice-current manifested in the drift depositions.*

The following are the principal facts as to the deposition of the till:

(1) The till of the New Haven region is most abundant along the eastern declivity of the western border, east of the

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* Trap bowlders occur sparingly on the eastern part of Long Island, and a few reached even Block Island. Sandstone fragments have the same range but are far fewer, because less durable. Block Island is nearly east of New Haven, but S. 20° E. from the Triassic of central Massachusetts. To the westward, some bowlders of trap are found about Port Jefferson, and rarely sandstone fragments. One chloritic bowlder, probably from two to ten miles west of New Haven, lying on the shore, measured 25 x 20 x 15 feet. Port Jefferson is south of southeastern Milford (Connecticut), and as Milford and other towns north of it, on the western border of the Triassic region, received numerous bowlders of the kind by the lower glacier current, the transportation to points so far west on Long Island is not surprising. (*Western* Long Island received its trap and sandstone bowlders, as was long since announced, from New Jersey and southern New York.)

† The movement of the great glacier, over southern Connecticut, in a direction *at right angles* to the Sound-ice implies that there was an equable slope in the surface of the glacier toward the Sound, and hence that the ice-surface over the Sound was nearly uniform from west to east, although the eastern end is half a degree farther north than the western.

Maltby Park valley (the central north-and-south depression of this border), where the depth is generally from 10 to 20 feet.

(2) The Maltby Park valley has, in general, little till over it, the surface being largely one of bare ledges and intervening marshy areas.

(3) But at one place in the eastern half of this valley (*Rd*, on the map, p. 342) *the till has a depth of more than* 107 *feet; and this piling up of till made there the isolated Round Hill* (as it is called), and gave it a height of 304 feet above mean tide, while the hills of the western border just east and southeast are only 140 to 200 feet high. Moreover these hills, and the surface along the road south of Round Hill, have not enough till to conceal the jagged rocks.

(4) The broadly rounded hills of southern Orange within three miles of the Sound, 200 to 280 feet in height, are deeply covered with till—the depth in some parts 40 feet or more.* Farther from the Sound, the till is usually of less depth, and rock-exposures are not uncommon.

The unusual amount of till and bowlders against the eastern declivity of the western border has already received explanation (p. 348).

The existence of bare ledges and little till over the Maltby Park valley is evidently a consequence of denudation; the region was swept by deep waters from the melting glacier—part going southward, directly to the Sound, with a pitch of 30 feet a mile for the four miles, and the rest northward into the valley of West River north of Westville.

The third feature mentioned is of less obvious explanation. Round Hill stands prominently in view from all directions. This isolated feature, its form, and the height of the surrounding region are shown on the following map. The great depth of the till at the summit had seemed probable from the fact that, unlike the other hills, it has no outcropping rocks over the upper third of its height; but it was *proved* by an excavation for a well made under the orders of Mr. R. M. Burwell, the owner of the place. The well was carried down 107 feet through the firmest of stoney and somewhat clayey till before water was obtained, and even at that point rock had not been reached. The highest outcrop of rock on the sides of Round Hill is at 174 feet above mean tide.

Another remarkable feature of the region is a deep trench on the southeast and east sides of the hill, only 118 to 130 feet above sea-level, something like the trench around a fortified acropolis.

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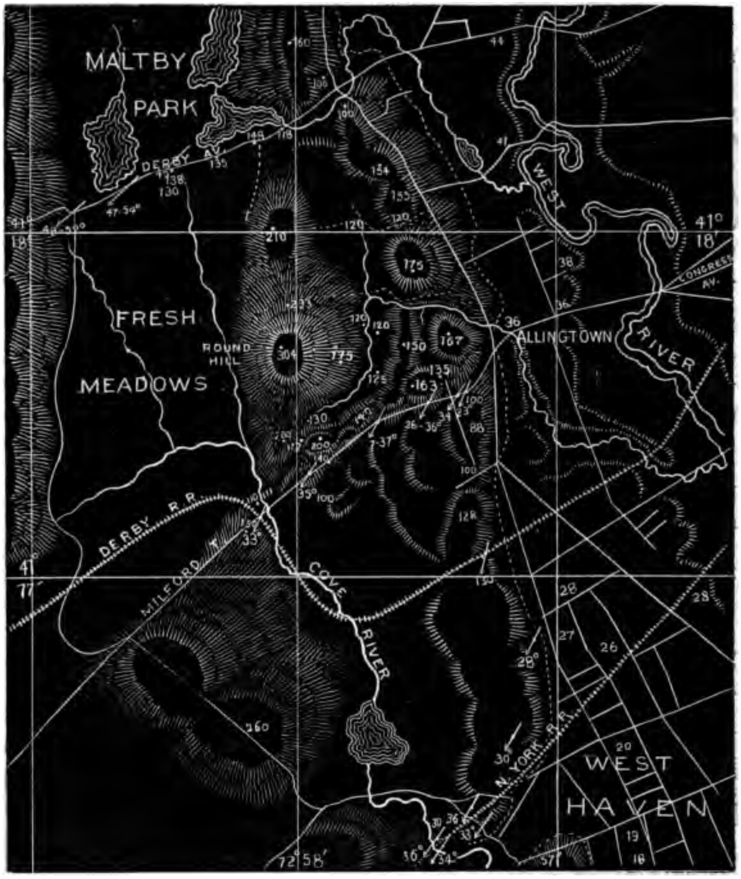
* On Shingle Hill, a little to the southwest of the region included in the map, an excavation for a well passed through 40 feet of till; on other hills, several wells go down 20 to 35 feet.

Round Hill is elongated northward—N. 8° W.; and half a mile off in that direction the height is 210 feet, and the depth



Map of Round Hill and vicinity, on the western border of the New Haven region.

of till is at least 21 feet, as found in a well-digging. It is also lengthened in the direction S. 10° W.; and only here is the slope an even one—a fact represented in the map above.* The hill thus covers and fills the eastern half of this part of the Maltby Park valley. At its western foot flows Cove River, the stream of the valley. Across this stream, another rise immediately begins, that of one of the deeply till-covered hills of southern Orange; so that the Maltby Park valley is here filled also over its western half, and consequently its breadth in this part is reduced to about 40 yards—although three-fourths of a mile wide just north. It is evident from the features of the region, moreover, that the depositions of till to the westward are essentially a continuation of those of Round Hill; that the valley was here to a considerable extent obstructed by the depositions; and that part of the flood waters from the melting glacier, besides making a lake above, flowed westward and joined the river-course next west, that of Indian River, the extensive flat meadows of Cove River north of the obstruction being elongated in that direction.

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* It has the constitution, as the description shows, of the "lenticular hills" of Professor Edward Hitchcock. But the quality *lenticular* is not an essential feature of such till-made hills, though common, as it is, and for a like reason, of many of the rocky ledges of the same region.

With reference to the origin of Round Hill, we note that the direction in which it is elongated is most nearly that of the *lower*, or valley, ice-current; and if we regard the more southwestern depositions as its continuation, the direction becomes S. 10°–15° west, which is yet nearer the course of that current, though still differing by 15 to 20 degrees. The actual direction of the ice-movement around it is registered at many places in glacial scratches. The courses are indicated on the map by arrows. They average S. 33° W. to the south and southeast of the hill, while to the north, the directions S. 45°–56° W. occur.

It is plain, from these facts, that the making of the solitary hill cannot be accounted for on the supposition of an eddy in the flow of the ice. The uniformity in the course of the scratches shows that there was no eddying.

The position upon the western border, where there were large drift depositions, and must have been, as already suggested (p. 348), the frequent opening of crevasses, may have had something to do with its formation. But no *line* of crevasses would have made so local a deposit.

Another point with regard to its position is its nearnesss to the Sound—the distance about three miles; and in this fact and the preceding, in connection with the character of the ice-movement, we have apparently the only data for an explanation. Over the Sound and its borders, the lower or valley ice-stream became warped around into the course of the general glacier-mass. This forced bending must have produced its greatest crevassing effects over the southwestern part of the valley region, within the plane of contact between the upper glacier stream and the lower—a plane that rose from the surface of the Sound at a small angle; and these effects would have been at a maximum in the part of the glacier where this plane intersected the north-and-south crevassed course of the western border. The existence is therefore probable of a knot of profound crevasses on this border region, at some point of greatest pressure, not far from the Sound; and, if a fact, a stream of water, or river, from the upper surface of the glacier may have here plunged down—like some rivers in glacial Greenland—causing a local deposition of the stones and earth that were in the ice, and thus have located and formed the till-made hill.

If the change of course were due only to the slope of the upper surface of the ice *at the place* it might have gone forward quietly. But if partly due to pressure from the northward along the valley there would have been the resistance and wrenching supposed.

The plunging waters would account also for the size and position of the half-encircling valley, cut in the schists about Round Hill; for this valley's being mostly free from drift; and for the trench which is its continuation eastward to the New Haven plain; for this was the way of discharge of the descending waters.

But the stream of water descending a crevasse could deposit only the drift encountered in its course on and through the ice; and wherefore then so high a pile in Round Hill? And why were 19-20ths of the drift in the hill the contributions of the valley or lower glacier current?

The height is evidence of long-continued deposition.

The valley source of the material proves that the drift of the glacier was mostly confined to the lower ice.

The mixture along with the trap and sandstone of some porphyritic gneiss, quartzyte, etc., from the northwestward, and the increased amount of the same in the western part of the hill, shows that the upper ice-stream was supplying material at the same time with the lower, though in much smaller amount.

The height of the hill, in connection with the nature of the material, indicates, further, that the lower, or valley, ice-stream had a depth in that region of at least 300 feet.

Round Hill is an example of a "kame." It is probable that the Andover kames were located by *crevasses* in the glacier that overlaid the region when the material was deposited.

Other facts bearing possibly on the origin of Round Hill will be presented in the following part of this paper—On the Terrace (or Champlain) formation of the New Haven region, its deserted valleys and its "kettle-holes."

Conclusions deduced in the preceding pages.

1. Two movements existed in the glacier-ice—a lower along the valley, an upper crossing it obliquely.
2. The two movements were simultaneous.
3. The upper ice kept its motion over the southward-flowing valley-ice quite across the Connecticut valley in Massachusetts, and across ten miles at least of its breadth in the southern half of Connecticut.

4. The lower or valley ice-stream was most rapid when the general glacier was of maximum thickness.

5. The glacial flow probably ceased when the melting was half completed, except in the mountain regions and some special localities elsewhere of limited extent; in which case, the disappearance of the general glacier did not end in leaving one or more long local glaciers in the lower half of the Connecticut valley.

6. Both the upper and lower ice-streams transported drift-material. The material from the upper that sunk into the lower stream was carried by it south-southwestward and deposited with the drift of the latter, and often against the eastward slopes of obstructing ridges.

7. The lower ice-stream lost its own direction of flow on reaching Long Island Sound, and took that of the general glacier mass across the Sound and Long Island.

8. The obstruction to flow in the western border of the New Haven region was the cause of crevasses and much drift deposition; and between this action and the warping around of the valley ice near and over the Sound, causing intersecting crevasses, the high local till-deposit of Round Hill was produced.

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ART. XIII.—*Phenomena of the Glacial and Champlain Periods about the mouth of the Connecticut Valley—that is, in the New Haven Region;* by JAMES D. DANA. (With Plates I and II.)

IN the last volume of this Journal the phenomena of the Glacial era in the New Haven region were described and discussed. It remains to describe—

II. THE PHENOMENA OF THE CHAMPLAIN PERIOD, OR THE CONSEQUENCES OF THE GLACIAL FLOOD IN THE NEW HAVEN REGION.

In order that the facts connected with the flood-deposits may be clearly understood the map used for illustrating the former paper is here reproduced (Plate I) with the area of the great flood-plain or terrace-formation colored. The scale of this map is *four-tenths* of an inch to the mile. Another map on a much larger scale—*two inches* to the mile—of the middle portion of the region is presented on Plate II, giving the details with regard to the topography along the valleys and over the plain, the heights above mean tide, and by contour-lines the features of the adjoining country. The dotted line at the base of the hills is the boundary of the flood-plain or terrace-formation.

The basis of this map is a reduction from the Bache Coast Survey Chart, referred to on page 343 of the last volume. The contour-lines across the plain have been omitted, and instead the actual height of the plain above mean-tide level from the Sound northward is in figures. These heights have been obtained by levelling, using as a base the heights of street curbs from the Report of the City Surveyor, and occasional points along the contour-lines of the Coast Survey chart. In all cases in and about the City of New Haven they give the *original* height of the plain. They are not always the present actual height, for city grading has made large changes; but happily some portions of the plain still remain in places where the buildings are most crowded. Outside of the crowded portion of the city, the plain is still mostly undisturbed except adjoining or along the roads crossing the valleys. Moreover, the shore-line along the head of the bay is restored to its former outline. The tidal flats along the rivers are cross-lined. The contour lines are for every 20 feet; in the Coast Survey chart mean high tide is the base, but the heights in the map are above mean tide, which is 3 feet below mean high tide. The map (Plate II) gives the original square of the city, half a mile each way, as laid out in 1638; the city now extends over the whole breadth of the map.

Before describing the "Kettle-holes" of the plain and the valley-like depressions that look like deserted river channels, it is necessary, preparatory to a discussion of their origin, to review briefly the facts relating to the transporting agents of the region, although the facts are contained, for the most part, in former papers by the author.

I shall treat *first*, of the rivers; *secondly*, of the deposits made by the flooded rivers; *thirdly*, of the depressions over the flood-plain or terrace-formation.

1. *The Rivers.*

The order of size in the three streams which traverse the New Haven Region on their way to the Sound, is now as follows:

	Length.	Approximate drainage-area.
1. Quinnipiac River	33 miles	120 sq. m.
2. Mill River	15 "	50 "
3. West River	15 "	38 "

In the era of maximum flood the relative rank of the first two rivers was reversed, through a gain in length, on the part of Mill River, of 15 miles from the Quinnipiac, the upper half, and also the larger part of Farmington River. (This Journal, xxv, 441, 1883). The size of the three streams thus became—

	Length.	Drainage-area.
1. Quinnipiac River	18 m.	65 sq. m.
2. Mill River	75 "	450 "
3. West River	15 "	38 "

The first two of these streams were changed by the flood also in the altitude of their sources. Mill River, as a consequence of the addition of the Farmington, drained the high plateau of southwestern Massachusetts and northwestern Connecticut, one of the Massachusetts branches commencing near the Becket Survey Station, which has a height above the sea of 2194 feet, and another near the Sandisfield Survey Station, 1698 feet. The abbreviated Quinnipiac flowed from regions mostly less than 300 feet above the sea, only very short lines on trap ridges extending higher. West River flowed, as before, from the high town of Bethany, averaging 500 feet in elevation, above the sea-level.

But the working force of these streams and their influence on the features of the New Haven deposits depended much on their slopes just north of and within the region, and especially south of the latitude of the Mt. Carmel gap. The level of maximum flood in the latitude of the gap, as determined from the height of the upper terrace, was (1) on the Quinnipiac 70 feet above mean-tide; (2) on Mill River 118 feet, or 48 feet higher than on the Quinnipiac; and (3) on West River, 300 feet. Nine miles south, in the line of the head of New Haven Bay, the normal terrace-levels, and therefore flood level, was about 40 feet above mean tide. Hence for the interval, the descent was

	Descent in 9 miles.	Descent per mile.
On the Quinnipiac	30 feet.	3⅓ feet.
On Mill River	78 "	8⅔ "
On West River	260 "	29 "

Thus the Quinnipiac was relatively feeble not only through its smaller supply of water, but also in its much less slope over the northern part of the New Haven region. Even West River was a stream of more power. In view of the relation in drainage areas and slope, I am led to conclude that the energy or effective force of these streams, the Quinnipiac, West River and Mill River, may be approximately represented by the ratio 1 : 4 : 25.

The slope of the land was probably less than now through a change of level, as deduced in a former paper; but any diminution of slope would increase, not diminish the contrast; for 2 feet less would be a large deduction from 3⅓ feet, but from 9 or 29 very small.

At the present time the tides extend up West River to Westville, and up Mill River to Whitneyville, in each case 2½ miles north of the latitude of the head of New Haven Bay. On the Quinnipiac they reach 7 miles north of the same line, or a mile above North Haven; and the four more northern of the seven miles are over very broad tidal meadows, as shown on Plate I.

2. *Deposition by the three streams.*

The three rivers emerged from their valleys on passing the extremities of the West Rock and East Rock ridges; thence they worked to some extent unitedly. This united action is proved by the fact that the plain from this line southward is continuous across its breadth of 4½ miles, and has nearly a common normal height, along east-and-west lines. Moreover, the deposits have throughout the same kind of structure and constitution, the flow-and-plunge style of cross-bedding being common in all parts, and the whole formation bearing evidence of simultaneous fluvial origin.

Further, the work of the several streams as measured by the deposits they made corresponds well with the estimate which is given above of their relative capability.

a. The Quinnipiac River.—The *Quinnipiac* made deposits of sand, with some fine gravel, on its east side, east of its present broad marshes, but almost none on the *west* side; which fact is evidence that the river transported but little, and that the material of the east-side deposits were mostly from tributary supplies. Along the borders of the Quinnipiac meadows there are clay-beds; but these are bottom or early deposits of the terrace formation, of quiet water origin, not those of full or half flood. They appear to rest on the unstratified drift or till that covers the sandstone, and derived the clay from the till.

South and southeast of East Rock, a high terrace, full a mile wide, stretches from Mill River eastward to Fair Haven, and for four-fifths of this distance it fronts, or is south of, the wide Quinnipiac meadows. Topographically it is a Quinnipiac terrace; and yet not so in origin, for it is in reality, as shown beyond, a *Mill River terrace.*

Thus the Quinnipiac has little to show of its work in the New Haven plain.

b. West River.—In contrast with the Quinnipiac, West River, on the west side of the New Haven region, contributed largely to the plain. Its terrace depositions south of Westville are three-fourths of a mile wide on the *west* side of the river alone. About Westville, where the stream escaped from its valley, the deposits are of the cobble-stone kind for a depth from the top of 30 feet or more, and they are but little less coarse on the east side of the river, where it received the contributions of Wilmot brook. The coarseness gradually diminishes southward; and three miles south, about its mouth, the deposits consist mainly of sand—a change attributable to loss of velocity.

c. Mill River.—Mill River, the great central stream, spread its flood waters across the whole region, mingling its depositions with those of West River on one side, and, on the other, taking possession as above stated, of the Quinnipiac valley. The latter result, like the former, was a consequence of its great slope and volume. The hurrying stream passed the Whitneyville gap at a level full seven feet above that of the Quinnipiac just east of it; and on reaching, a mile below, the end of the intervening East Rock ridge (at E) it must have made a violent dash eastward, carrying as it went its load of sand and gravel into the Quinnipiac area. The coarse gravel deposits of the terrace on the Mill River side attest to the violence of the flow at this point; and a diminution of coarseness eastward corresponds to the loss of velocity as the waters spread eastward. Moreover the terrace deposits to a depth of 25 feet from the top have the cross-bedded structure that would have been produced by the flow of Mill River, proving that it had complete control in the deposition. The direction of dip in the cross-bedding is the reverse of that in the finer and redder beds of the *lower* 25 feet, and the transition is an abrupt one.* Only this earlier portion, made before the waters were above half flood height, was stratified by the Quinnipiac current.

The torrential character of Mill River in the Whitneyville gap is attested to by a number of large pot holes made in the sandstone of the west bank near the flood-level of the era. One of these pot-holes (4½ feet wide and 7 deep) may now be seen by the road side, 140 yards above the dam and nearly 60 feet above tide level; and two others were opened to view and cut away in the grading of the road a few years since.

Mill River, therefore, was the chief source of the stratified drift or terrace deposits of the New Haven region. We have, consequently, to look to it for an explanation of the more prominent features of the New Haven plain.

The general southward slope of the terrace-formation from Mt. Carmel to the Sound has been already given. The facts are still better before the reader on the maps accompanying this paper, the height being stated on the larger map, in figures. A review of them in this place is therefore not necessary.

3. *The depressions of the New Haven plain.*

The depressions of the plain are:

(1.) The flood-made river-channels, bounded for the most part by the terrace-fronts facing the existing streams.

(2.) Depressions in the plain made by drainage from its surface.

(3.) The area of a low terrace, of 20 to 25 feet elevation, bordering the bay on the north side, and Mill River on the west and less widely on the east.

(4.) Two long depressions that look like portions of large river-channels.

(5.) The "Kettle-holes."

(1.) *The flood-made river-channels.*—These broad river-ways of the flood era answer to the channels of the modern stream between the terrace-fronts—the banks as they are called—of its modern flood-ground, and had, as I have elsewhere explained, the same mode of origin. Like them: (1) they were made along the course of the greatest velocity in flood-time; (2) their depth below flood-height is (excluding some later erosion at bottom) the depth of scour, which depth was dependent mainly on the velocity and the kind of bottom; and (3) the bordering terrace and terrace fronts are a consequence of loss, on either side, of velocity in the transporting waters resulting in deposition.

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* See Geol. of New Haven Region, Trans. Connecticut Acad., vol. ii, 1870, and this Journal, III, vol. i, p. 173, where the section of the formation showing the reversed dip is introduced.

(2.) *Depressions from surface drainage.*—Of the depressions which look as if referable to surface-drainage, two are of special interest. These are *East Creek* and *West Creek*, east and west of the original New Haven square, as shown on the map of Plate II. Both streams flowed in part between abrupt terraces for nearly half a mile from the bay, and the latter of the creeks admitted the ships of the early colonists for half that distance;* but under city grading both creeks have disappeared, and the channels are fast becoming obliterated. The map renders further description of them in this place unnecessary. The size of the channel of West Creek between the terraces, and certain features common to both soon to be stated, lead to the conclusion that they may have a long history, even antedating the existence of the plain, and are only in some later modifications a result of surface-drainage.

(3.) *The low-terrace area.*—This area, as the larger map shows —by the heights given on it and a band of shading—extends from the bay and West Creek valley northeastward over the lower half of the central square of New Haven and onward for a mile up the west side of Mill River, and also over a small region east of the southern part of this stream. In height the terrace is 15 to 20 feet below the normal upper terrace. On glancing over this area on the map (Plate II) and noting its relations to Mill River channel, it is manifest that it is simply the area of a low Mill River terrace; and the facts show that its existence was determined by the velocity of the waters during the flood; that it lies where the depth of scour was too great for the building up of the terrace-deposits to their normal height, or that of the New Haven plain elsewhere. Part of the evidence consists in the exceedingly coarse, largely cobble-stone, character of the underlying gravel. The direction of the band of coarsest gravel indicates that Mill River followed a nearly straight course from Whitneyville to the head of the Bay, this being one of the numberless examples of a straight cut made in rivers by the great flood.

The low terrace is hence one of the phenomena manifesting the power and influence of Mill River.

(4.) *The long depressions resembling fragments of former river channels.*—These channel-like depressions are called the *Beaver Pond Meadows* and *Pine Marsh Creek.* Their location is given on both maps, and their special features on the larger one, Plate II. As there seen, they stretch southward through the middle part of the New Haven plain, between Mill Rock on the east and Pine Rock on the west, and each is about 1⅜ths mile long.* They are sunk 25 to 35 feet below the level of the plain, and are confined for the most part by terrace fronts of this height. They have a width mostly of 800 to 1,000 feet, and a bottom of peat meadows, though with some encroaching areas of sand deposits; the level of the marshes in the Beaver Pond depression is 27 feet above mean tide, and in the Pine Marsh, 33 to 35 feet. They are much like the West River channel-way between its terrace fronts; or, rather, like fragments of it, for they are marvelously short for the great breadth and depth. The western depression—that of the Beaver Pond Meadows—is wholly isolated from any of the rivers of the region both to the north and south, but has a lateral connection by a valley with Mill River valley. Each has its stream, one emptying by the *lateral* channel referred to into West River, the other joining Mill River by its *north* end. These streams, although not two miles long, which is very short for the great valley they occupy, are abundant in waters, that of the Beaver Pond depression supplying a mill the year around. These copious waters are almost wholly *subterranean*—whence it is that the deeper pools do not freeze over with the thermometer at 0° F.

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* The vessels came to anchor at what is now the corner of Congress Avenue and Oak Street.

As shown on the map, the more northern of the two depressions, Pine Marsh Creek, comes to its southern end abruptly in the plain southwest of Mill Rock; while the other, the Beaver Pond depression, begins almost as abruptly just west of this place; the terrace-plain between them is for the most part at its normal height.

The depth through the peat to hard bottom is another singular feature. In a recent survey of the Beaver Pond Meadows, by Mr. Sylvanus Butler, under the direction of the city of New Haven, the depth through the peat to firm gravelly bottom was found, at one place just northeast of the outlet, to be 52 feet, *which is 25 feet below the level of mean tide.* The soundings were made along the water-course, which is not in all parts the line of greatest depth. A little outside of it, and nearly a third of a mile south of the above-mentioned place, other soundings of 48 to 52 feet were obtained.

No borings have been made through the bottom gravel to the underlying sandstone, and hence the actual depth of the trough to solid rock is unknown; we know only, from the fact just stated, that it is more than 25 feet below mean tide. From this it appears to be certain that the Beaver Pond channel is not simply a depression in the plain or the terrace deposits;

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* The Beaver Pond depression terminates southward near the junction of Goffe and Crescent streets, and extends northward along the west side of Crescent street. The Pine Marsh depression has its southern termination near the extremity of Shelton Avenue, north of Morse street.

on the contrary it covers probably an excavation in the subjacent sandstone. On the western margin of the depression, rise the low "Beaver Hills," and these are sandstone hills with a thin covering of unstratified drift. These hills (see map) have the trend of other sandstone hills of the region whose outline was plainly determined by the direction of movement of the ploughing glacier.

No similar soundings have yet been made in the Pine Marsh depression. But the fact that the waters are subterranean, and its close resemblance to the Beaver Pond depression in all its features, are favorable to the conclusion that the two are alike in depth of excavation and of one mode of origin.

As to *origin*, we have the following basis for a conclusion:

1. The resemblance in each to the channel of a great river, both in width and in steep terrace-fronts.

2. The depth of the trough :—that of the Beaver Meadows extending much below the sea level, as if channeled out of the New Haven sandstone region by the glacier.

3. The fact that the Pine Marsh depression or channel-way, and Mill River valley for three miles next north, have approximately the same compass course, coincident with the glacier flow, making them one channel-way; and that this channel-way points directly through the open center of the New Haven region (between Pine and Mill Rocks) nearly toward the head of the bay (which bay it is to be noted, is the termination of the Connecticut river valley or trough); while the course of Mill River *below* the junction with Pine Marsh Creek makes an angle of 40 degrees with that of the glacier-flow, and passes through a narrow gap, in trap, at Whitneyville.

Objections to the conclusion here indicated are apparent (1) in the abrupt southern termination of the Pine Marsh depression, and (2) the isolation of the Beaver Pond depression.

Before considering further this question of origin, the facts respecting the "Kettle-holes" need to be surveyed.

4. *The Positions and Characteristics of the Kettle Holes.*—The kettle holes are nearly seventy in number. Of these, (1) *twenty* are situated on or near the borders of the Beaver Pond depression; (2) *thirty*, by the Pine Marsh depression; and (3) *seventeen* at Augurville, near the junction of Sluice-way Brook with Mill River. The map Plate II shows their positions.

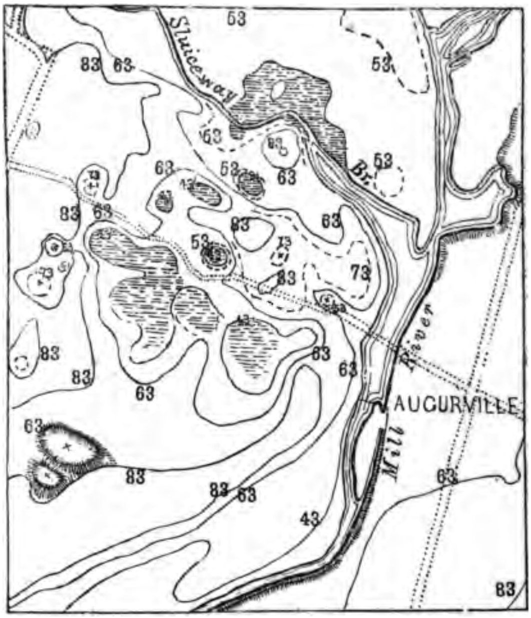
All occur in the *stratified drift*; that is, the well-bedded material of the New Haven plain, or that of the terrace-formation, gravel-made and sand-made portions irrespectively, away from all *unstratified* material, or till. This formation in their vicinity has its usual horizontal bedding and flow-and-plunge structure. Whether the horizontal feature usually extends quite to the edge of the kettle-hole has not been ascertained, because of the want of exposed sections. In a section of one near Pine Marsh Creek, made in laying out a new track for a railroad, an upper layer of the terrace formation, about 6 to 8 feet in thickness, followed down the steep slope of the depression conformably to its surface; but this single case is not sufficient for any general conclusion; it may have been due to a slide, though not looking like it.

The kettle-holes are usually isolated; the coalescence of two or three in a single oblong or irregularly-shaped depression is also common. They vary in diameter from 100 feet to more than 500 feet, and in depth from 15 feet to 50. The sides have the same slope as the terrace fronts along the river-channels, or generally 30° to 38°. They are often dry (if shallow), but generally are marshy at bottom, and not unfrequently contain a pond of water.

The distribution, sizes, forms, positions, and relations to the Beaver Pond and Pine Marsh depressions of the kettle-holes are so clearly exhibited on the accompanying map (Plate II) that detailed descriptions are not necessary. It is seen that the most of them range along parallel with these depressions. On the west side of the Beaver Pond depression the holes are partly in coalescing groups of two to four ranging parallel with the depression, or oblong in the same direction. On the east side are other oblong holes which are *transverse* in direction instead of parallel, yet still have an undoubted relation in position to the great depression.

The cluster of kettle-holes near Augurville (see map, Plate II), at the junction of Sluice-way Brook with Mill River, is peculiar in its position. A map of the region on a larger scale (5 inches to the mile) is here introduced to show better their forms and their position in relation to the two streams. The map is from the Coast Survey chart and gives its contour lines. The kettle-holes vary from small circular shallow bowls to large irregular depressions having a marsh at bottom which is 45 feet below the surface and on a level with the water in the river. As the contour-lines show, they do not connect directly with the Mill River Channel. The contour line of 83 feet occurs among them as well as on the western border, and that of 63 between them and Mill River.

Sluice-way Brook is the modern representative of the stream that, in the time of the glacial flood, came down from the Mt. Carmel gap (see map, Plate I), and had its chief source in the waters above the ice-dam through the sluice-way at its western end, as described in volume xxv of this Journal (1883). The sluice-way waters, after passing the barrier of trap at the dam, flowed southward (as has been described) in a channel, 25 or 30 feet wide, worn by the waters out of the red sandstone, and then—re-enforced by tributaries from high hills to the northwest—followed the valley of the existing brook for three miles before reaching Mill River at Augurville. The descent in this distance is 25 feet a mile, while that of Mill River from the dam to the same point was only 10 feet a mile. The two flooded streams came together with velocities corresponding to these different slopes; and the coarse gravel deposits at the place of junction, some of the stones a foot or more in diameter, are evidence of the violence of the sluice-way torrent.



Kettle-holes at the mouth of Sluice-way Brook.

4. *Facts bearing on the Origin of the Kettle-holes and the long channel-like depressions.*

1. The relations between the kettle-holes and the Beaver Pond and Pine Marsh depressions, above pointed out (as exhibited on the map), make it almost certain that there was community in origin for the two if not unity in method of origin.

2. This community of origin as regards the two great depressions was, with hardly a doubt, unity in origin and method. For they are partially connected by outreaching arms and kettle-holes. From the southwest angle of the northern or Pine Marsh depressions an arm extends out *westward*, and at the end

of the arm there is a large and deep kettle-hole continuing the line toward the Beaver Pond depression. Further, the latter depression just southwest stretches out two long arms *eastward*, suggesting former junction. A dozen other kettle-holes lie to the south and southwest of the Pine Marsh depression; and other arms extend toward them from the Beaver Pond area. Although the plain around has the normal height (as the map shows) the arms and kettle-holes look exceedingly (more so in the field than on the map) as if a former channel had existed and had become mostly obliterated by sand and gravel deposits.

3. A former union of Pine Marsh channel with the Beaver Pond channel almost necessarily implies a continuation of the channel to the head of the bay; and such a continuation is plainly indicated by the ranges of arms and kettle-holes extending from the *southeastern* portion of the latter channel toward and into the *East Creek* channel (see map). The arms leading from the depression are in fact kettle-holes partially coalescing with it; and the kettle-holes make two almost continuous arm-like channels extending into the creek valley.* The southern of the two lines is over 1,000 feet long. Again, farther south, near the south end of the Beaver Pond depression, still another line about 2,000 feet long, consisting of two kettle-holes (one 500 feet in diameter with formerly a pond at bottom) and a long depression,† make another connection with the East Creek channel. A boring in this channel, ¾ *m. from the bay, descended* 40 *feet below mean tide before reaching rock.*

A connection of the Beaver Pond depression with *West Creek* can not be so clearly made out, and yet it has facts in its favor. East of south from the south point of the depression, separated by a low neck, lies a large (500-foot) marsh-containing kettle-hole.‡ In the same south-by-east direction, 2,000 feet away, commences the West Creek channel, which soon becomes 700 feet wide with a steep terrace-front on either side. The size of such a channel-way is out of all proportion to its mile-long stream; but it is well explained if there were once a connection with the Beaver Pond channel to the north of it.

4. The conclusion seems to be inevitable in view of all the facts just stated (including those before adduced, as to the depth of the Beaver Pond trough and the conformity of the Pine Marsh depression and Mill River north of it in course to the direction of glacier movement) that the two now isolated depressions are dissevered parts of the deep Mill River channel of the Glacial era; that East Creek and West Creek are

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* Munson street runs between the two ranges of kettle-holes.

† This depression is just south of Webster street.

‡ West of Goffe street, opposite the bell-tower square. It is much shallowed by city grading and will soon, like others, disappear.

within the boundaries of the same great channel as it passed into the greater channel of the bay; and that this broad Mill River channel of the Glacial era through the soft sandstone was deepened at that time, if not made, by the excavating action of the ice and running water. The phenomenon is one now known to have been a common result of the glacier flood, in which a stream had its Glacial-era channel partly obliterated by the depositions from the waters as the flood from the melting made progress. The deposits appear to have early blocked the channel, even before half-flood was reached, and thus forced Mill River to take its present course. It is probable that a diminished slope in the land aided the depositions in checking the stream.

The origin of the great depressions is thus traced to excavating-work in the Glacial era and subsequent depositions of drift material. They are the *unfilled* portions of the old channel, and were left unfilled, while deposition was going on so freely, because of the depth of the excavation, or, for parts of them, because of the position with reference to the main current. The waters of the rising flood made a new exit for each of them, the Beaver Pond depression having opened a western outlet to West River, and the Pine-Marsh depression taken its northern extremity for discharge into Mill River. The discharge of the Beaver Pond waters was of long continuance, and held on through the era of maximum flood; for the deposits of the terrace adjoining the exit channel are of very coarse gravel, while elsewhere about the depression they are of fine gravel or sand.

The mean width of the Pine Marsh and Beaver Pond depressions has been stated to be 1000 feet. But the actual width in some parts is 2000 to 3000 feet; and as these depressions are only what was left after the burial, the mean breadth was probably near the present extreme breadth, or at least *half a mile;* and this comports with the supposed size of the stream. The connecting lines between the Beaver Pond depression and East Creek are half a mile apart, and they may be the outer portions of the one broad channel half a mile wide. East and West Creeks are only two-thirds of a mile apart; and these may have been the sides of the channel at its mouth, for the channel would not there have been narrower but rather wider than to the north.

5. The *origin of the kettle-holes* remains for consideration. Their situation by the side of the great depressions, sometimes in lines parallel with them, and their lying also in lines more or less perfectly connecting the two depressions with one another and the more southern with West Creek channel, proves that they originated at the same time with the depres-

sions and under similar conditions. But was it by the same method?

The kettle-holes cannot be attributed to the removal of an underlying stratum of clay or of limestone, for we have no evidence of any clay or limestone underneath. Again, it is not probable that sands of the underlying beds could have been carried away by subterranean drainage, for the subterranean waters of the region are those within the terrace formation itself, in which movement is necessarily very slow, transportation difficult, and the determining thus of isolated kettle-holes hardly a possibility under the most favoring circumstances.

Besides these explanations, two remain for consideration:

(1) That they are, like the larger depressions, unfilled portions of the old and deep excavations which were left unfilled because of their depth, position, and the current-action in the waters.

(2) That they are the sites of ice-masses which melted finally only after the terrace-formation was wholly or nearly completed, and which hence left holes where they lay. This origin of kettle-holes through the agency of ice-masses was suggested long ago by Professor Edward Hitchcock.*

The theory of left or stranded ice-masses appears to apply to some cases; but not so here, for the following reasons:

In the New Haven region, (1) deposition of the terrace-material and (2) the making of the kettle-holes must have gone on together, as the stratification around the kettle-holes shows; and the latter were formed chiefly along either border, or the course, of the great central water-way, and that part of the water-way which became divided by obstructing depositions. Consequently, if ice-masses were concerned, they were stranded masses from the river, not ice left in place by the retreating glacier. Further, since these holes are 25 to 50 feet or more deep, the ice-masses must have been in place in the *early* part of the flood and have projected high above the waters during its whole progress.

Some of the difficulties are thence the following:

(1) In the early part of the flood (when only finer sand deposits of the terrace formation were in progress), there is no reason to believe that water enough existed in the stream to have floated masses 100 to 500 feet or more in diameter and 50 feet or more thick; for 50 feet of depth, at least, would have been required. The above are minimum numbers as no allowance is made for waste by melting.

(2) The waters which flowed by the stranded masses through the progress of the flood, deposited in their close vicinity beds of sand and gravel having the flow-and-plunge structure, and

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* Report on the Geology of Massachusetts, 4to, 1841, ii, 370.

in some parts beds of the coarsest gravel; they were hence rapid and plunging waters, and the stranded ice-masses where exposed to them could not have remained long unmelted.

(3) The latter half of the era of the terrace depositions was that of the closing part of the melting, and therefore not the era of glacial cold, but one of milder airs, such as predominated in the Champlain period; and hence the winds would have helped in the dissipation of the ice.

The other explanation, also—that the holes are places unfilled by depositions because of their depth and for the other reasons mentioned—has apparently its difficulties. It is a matter for surprise that where so great depositions were in progress so many holes of the kind should have been left in the plain; and also that the terrace-formation should have been so generally built up to full normal height quite to their margins.

Such results lose some of their seeming improbability when the process of deposition is fully considered; that

(1) The shallowest part of a water-way, as its reefs or bars, are most likely to take the depositions because they occasion by friction lessened velocity and transporting power; and hence the deeper parts do not generally lose in depth by deposits, but become narrowed by the down-stream extension of the sand-reefs, and deepened also owing to increase of velocity in the narrowed passages; (2) that consequently, in a great flood, if the amount of transported material is large, almost as much as the waters under the rate of flow could carry—as was the fact during the flood from the melting glacier—the reefs, or the flood-grounds, would be built up rapidly toward flood-level through the abundant deposits, and become extended at flood-level height in the direction of the flow, and thus the shallowest parts over these grounds might or would have taken the larger part of the depositions; (3) that when an isolated depression was encountered, the waters would have taken often some rotary movement, which would have promoted abrasion and removal, and caused deposition outside instead of inside.

The writer, while admitting the sources of doubt, inclines to adopt the latter explanation of the New Haven kettle-holes rather than the former for the reasons already stated.

(1) At the time of the supposed stranding, the ice-masses could not have had water enough to float to their places.

(2) Under the conditions that existed during the flood, the isolated ice-masses could not have lasted long enough, or a hundredth part of the time, necessary to keep the spaces open.

(3) The intimate and systematic association of the kettle-holes with the great Pine Marsh and Beaver Pond depressions and East Creek appears to put all into one category as to method, as well as community, of origin.

The cluster of kettle-holes at the mouth of Sluice-way Brook may be looked upon as a case similar to those of the great depressions just mentioned. For the large irregularly-outlined kettle-holes making the center are much like a small example of a Pine-Marsh depression with kettle-holes bordering it. It is probable that in the Glacial era the course of Mill River from Centerville *southward* was a straight one right through the deep kettle-hole area, where the violent waters of Sluice-way brook struck (see map); and that the eastward bow-shaped bend of the present stream at Augurville, was a consequence of the depositions of drift, which forced the Mill River channel to a more eastward position.

CONCLUSION.

The history of the New Haven region during the Glacial era probably included the deepening if not the excavation, by ice and water, of a wide channel passing through the center of the region from Centerville to the head of the bay—the Mill River channel. The moving glacier had to rise over the trap ridges, Mill Rock and Pine Rock, standing on either side of the passage, and may have ploughed all the deeper into the sandstone region between them.

At the beginning of the Champlain period—dating it from the beginning of the northern subsidence of the land (actual or relative) that characterized it, which was followed by the melting—the river commenced its increase in waters and transportation. But the progressing subsidence just referred to tended to cause diminished velocity, which, there is reason to believe, the increasing depth of water hardly balanced; and hence the channel, as it widened southward (below the mouth of Pine Marsh Creek), became obstructed in places by sand-bars; and these increased as the flood made progress, and coalesced into the wide terrace formation—that of the New Haven plain. Mill River in this way was early shut off from its central way to the bay by the depositions of the plain, only fragments of which survive in the Beaver Pond and Pine Marsh depressions.

A westward set in the water and its depositions would have resulted from the earth's rotation, and either through this means or some other the river was forced to take its present eastward channel against the sandstone hills of the "Quinnipiac" Ridge. The Beaver Pond and Pine Marsh depressions, after their isolation, continued to be filled full with waters from the flood until maximum flood was reached, and they remained deep depressions, but shallowed in part by sands, because of the river-like discharge of their waters, one into West River, the other into Mill River. These depressions and the kettle-holes were one in origin and history.

Note on the Glacial flood of the Connecticut River Valley.

As the explanations given in my paper on the Connecticut valley terraces* have been imperfectly understood, I add here a few words on the subject. Professor C. H. Hitchcock, in a paper read before the American Association in 1882 (Proc. Am. Assoc., p. 325), after accepting the distinction adopted by Mr. Warren Upham between "delta-terraces" and "highest normal terraces," and objecting to taking the so-called "delta-terraces" as the normal highest, as done for many localities by me, remarks that "if we are not required to accept the deltas as a measuring rod, we shall greatly reduce the depth of the stream and thus learn why the velocity as calculated by Dana was far too great."

No calculations of the velocity corresponding to the reduced depth are given.

In my paper I state that one prominent purpose before me in my investigations was to ascertain whether the so-called delta-terraces were true Connecticut valley terraces or not; and the conclusion reached was that the most of them so directly border the Connecticut valley and for so long distances (some of them for miles) that they could not have been deposited at the delta level unless the Connecticut river waters were at that level to transport and deposit. The tributary and the main stream must have risen in level together, as in all other floods, and I found that the so-called delta-terraces were, in general, the sand and gravel of the tributary deposited and arranged in beds by the on-flowing Connecticut. The flood-level deposits *now* made on the sides of a river where it receives one of its larger tributaries are evidently as much delta deposits as those made during the progress of the glacial flood; and yet they rise but little, where at all, above the flood plain of the main stream, and have no claim to so distinctive a name.

Again, if the level of the "highest normal terraces" of Upham are taken as marking flood-level, they indicate an impossible water-surface for the river, since the heights given vary greatly in a few miles.

At Barnet, the height of the "highest normal," as reported by Mr. Upham, is 166 feet above the Connecticut at low water; 10 miles below, it is 113 to 123 feet (while the mean pitch in the modern stream in this distance is 4½ feet a mile); 12 miles farther south, at Bradford, it is only 80 feet (the mean pitch in the river for the interval being 1½ feet a mile); 9 miles farther south, at Ely, only 60 feet (the mean pitch here being 1 foot a mile); then, only 2¼ miles farther south, at North Thetford, the height is 146 feet; and farther south, 170 to 180 feet for many miles. (The "Delta-terraces" are in part still higher).

Thus, within 33 miles, the following variations in the level of flood waters are indicated, if we take Mr. Upham's "highest normal terraces" as showing the water mark: 166, 118, 80, 60 and

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* This Journal, xxii, 451, 1881, xxiii, 87, 179, 360, xxiv, 98, 1882.

146 feet. Such variations in the water surface of a flooded stream in an open valley of nearly uniform pitch are obviously incompatible. The slopes are those of two face-to-face cataracts, the southern having a fall *northward* of more than 30 feet a mile. Mr. Upham has an explanation of these differences as to level, based on the assumption that the glacier-mass of the Connecticut valley made the flood and the terraces south of it *pari passu* with its retreat northward, he holding that it was a retreating ice-barrier retreating through melting, and thus keeping the flood up to flood-level south of it. This hypothesis (which has obvious objections, as I have shown) is not adopted or mentioned by Prof. Hitchcock.

Note on the two courses of the Glacier over the Connecticut River Valley.

The courses of flow in the glacier—that of the general mass and that of the valley—have been made out by me to be simultaneous on the theoretical ground that the flow in the direction of the valley—west-of-south—would have necessarily been most rapid, supposing the slope of the land the same, *when the ice of the valley to the north was thickest;* that the ice would have been thickest when the general glacier-mass was thickest, which was the time when the *southeastward* movement of the general glacier, or that determined by the slope of the *upper* surface, would have been most rapid. One condition would thus have produced the two results. This fact of two movements is not so difficult to understand when it is considered that the flowing of a glacier, however to be explained, is like that of a viscid liquid over an uneven grooved surface. It follows from the coexistence of the two movements that the upper stream did not cause, by its pressure in the direction of motion, so much friction between the lower ice and the east side of the Connecticut valley, or between itself and the bottom ice, as to prevent the valley movement. This friction would be too great to overcome when a valley was narrow and abrupt, or had a direction approximately transverse to that of the southeastward flow; neither of which conditions existed in the case of the Connecticut valley.

One fact referred to in my paper as sustaining the theoretical conclusions was this: that variations in the bottom directions of movement (shown by the glacier scratches) often accompanied quite small changes of form in the subjacent surface, and various directions occurred within short distances. It is exceedingly improbable that all these bottom courses should have existed also in the ice of the upper surface.

Another fact bearing on the question is presented by the *absence* from the New Haven region and the adjoining part of the Connecticut valley (and from the valley north through the State of Connecticut) of all traces of south-southeastward glacier scratches, and of underlying drift deposits derived from the north-northwestward. If the valley movement were *subsequent* to the southeastward flow and the latter had gone on through the chief part of the Glacial era, the earlier drift, or that from the northwestward, should be found in spots somewhere over the bottom of the valley, beneath the valley drift; and southeastward scratches as well as drift. But none such occur. The bowlders of the upper current, or those from the northwestward, are mingled with the valley till, occurring within it, and on top of it. All evidence opposes the idea that it was brought in before the valley movement supplied the valley drift; and all facts accord with the explanation given that the bowlders of the upper glacier current sunk into the lower or valley current, and were deposited by the latter. Some of the bowlders taken from the region *west* of the valley in Massachusetts were carried 70 miles southward without going eastward more than half way across the valley, or about 10 miles.

APPENDIX.

CITATIONS FROM THE AUTHOR'S PAPER ON "THE GEOLOGY OF THE NEW HAVEN REGION," PUBLISHED IN THE TRANSACTIONS OF THE CONNECTICUT ACADEMY OF SCIENCES, VOL. II, 1870.

[The chief points in which the views of the preceding memoir differ from those of the earlier paper whose title is above given, are those relating to the origin of the North Haven clay beds and of the sands of the plain north of that place, and the condition of the North Haven meadows during their deposition. Moreover, small changes have been made in the heights of parts of the New Haven plain. The following citations relate (1) to the subterranean waters and wells of the region ; (2) the evidences of a higher level of the land in the Glacial era; and (3) the discovery of bones in the North Haven clays. Some new facts have been added.]

I. SUBTERRANEAN WATERS IN THE NEW HAVEN PLAIN—HARD-PAN BENEATH THE BAY.

1. WELLS.—The following facts with regard to the *subterranean waters of the plain*, as illustrated by its wells, I have from Mr. D. W. Buckingham, and Mr. Philo Chatfield, whose personal observations in this direction have been extensive.

(1.) The water is spread widely beneath the plain, and is not collected in local channels; this accords with the sandy nature and near horizontality of the deposits that afford it.

(2.) The height of the water varies with the degree of humidity of the seasons, the extreme difference amounting to about two feet; it is ordinarily about three years in reaching its lowest level, and as many in regaining its highest.

(3.) In digging wells, water is not usually found until a firm gravelly layer is reached.

(4.) The water level over the extensive Beaver Pond Meadows is about 27 feet above mean tide (24 above high tide), and this level is constant the year round. Formerly it was somewhat higher, and, 60 years since, its ponds often afforded good skating in winter. To what height the springs would carry the water if the outlet were dammed up to a higher level is not known; it is altogether probable that, owing to the sandy nature of the enclosing banks, the water could not be raised much above its original level. The level of this great marshy area apparently determines the height of the water-plane in its vicinity and to the southward.

(5.) Over the central portion of the New Haven plain, about High street, back of the College grounds, and to the north toward the Beaver Pond Meadows, water is obtained wherever the height is 43 to 44 feet above mean tide level, at a depth of about 26 feet—in other words, the upper limit of water, or the water-plane, is here about 18 feet above mean-tide level; and the height of any spot over this region being ascertained, the number of feet of excavation required to reach water is approximately known. To the southeastward the water-plane dips toward the bay; its height at the corner of Church and Chapel streets, one-fourth of a mile from High street (where the height of the surface is 20 feet), is 6 feet, or 14 below the surface; and one-sixth of a mile farther southeastward, in State street near Chapel (where the height of the surface is 14 feet), it is about 3 feet, or 11 below the surface. Through Chapel street, between Church and State, and over the region either side, the depth to water is 12 to 14 feet, and in State street 11 to 12 feet. On the southwestern border of the High street region, along Oak street, the course of the old *West Creek* channel, water rises nearly to the surface, or to a level of 12 or 13 feet above the sea, the land here being low. Again in Grove street, on the other margin of the High street area, near the Cemetery, in the old *East Creek* channel, the water-plain is 20 feet above the sea; Sachem's ridge is near by.

In contrast with the above, we find that to the northwest of what we have called the High street region, beyond Dwight street, the water-plane dips toward West river, and falls even below the mean level of the water in the river, or that of the bay. Thus out West Chapel street, not far from its junction with the Derby avenue (where the plain has a height of 42 to 45 feet above mean tide), wells are sunk to a depth of 50 feet before water is reached; the latter depth is 5 feet below the level of the sea and of the river. I learn from Mr. P. Chatfield that the excavation for the well at the house now occupied by Mr. G. H. Scranton, on Winthrop avenue near Chapel street, was carried to a depth of 45 feet. Again, out Whalley avenue, at Hamilton Park not far from West river, where the height of the plain is 48 to 50 feet, the depth to water is 45 feet. But east of Whalley avenue, on Hudson street (west of the jail), the wells are only 25 feet to water. Hudson street is therefore within the limits of the central *high-water* region of the city, while Norton street is beyond it; and this fact is no doubt a consequence of its nearness to the Beaver Pond Meadows. Again, near the corner of Davenport avenue and Howard street, the level of the plain above mean tide is about 42 feet, and the depth to well-water 29 feet; and on the corner of the same avenue with Vernon street, 500 feet west of the latter, the depth to water is 25 feet.

The water-level in the Beaver Pond Meadows may be partly a consequence of the existence of the Beaver Hills along the west side. The Beaver Hills consist, beneath a thin exterior of sand and gravel, of sandstone. Now the dip or pitch of the sandstone in the New Haven region is almost uniformly either to the eastward or southeastward; and this would cause the water that falls on the hills to flow toward the meadows. The Beaver Hills extend southward and cross Whalley avenue in the vicinity of North and Norton streets, and probably extend under ground much farther south. They consequently make a *western boundary* to the northern part of what we have called the High street area. Hudson street and the jail are *east* of the line of the Hills, and therefore, within the high-water area; while Hamilton Park is to the *west* and far outside of it.

2. HARD-PAN OF THE HARBOR.—The following observations on the *hard-pan* beneath the harbor consist mostly of information obtained through the driving of piles, and the sinking of artesian wells. For the facts derived from pile-driving I am indebted mainly to Mr. C. R. Waterhouse and Mr. Sylvanus Butler.

a. At the head of the bay, near the foot of Greene street, in preparing the foundations for the Gas Works, a *hard-pan* layer was found at a depth of 31 feet below the level of the sea; the overlying material being harbor mud. The layer was 3 feet thick. On driving through it, by way of experiment, the piles went down through 40 feet of mud or loose sand, without finding another hard layer.

b. In the construction of the Chapel street bridge across the mouth of Mill River to Grape Vine Point, a little south of the Gas Works, the piles, starting from mean-tide level, penetrated 33 feet of mud and struck the hard-pan. The layer was so hard that the piles made but an inch or two at a stroke, and with 54 strokes did not go through it.

c. At the steamboat dock, 120 rods farther south, the piles passed through 25 or 26 feet of mud before reaching the hard-pan. A little to the west, at the end of the East street sewer, hard bottom was found (in 1872) at a depth of 48 feet; and at 40 feet at the end of the East street wharf, the material passed through being water 2 feet, mud 10 feet, coarsish sand 3 to 5½ feet, mud 8 to 10 feet, then hard sand down to the hard-pan.

At the end of the Meadow street sewer, near the railroad station, the hard-pan was reached at a depth of 39 feet below mean tide.

At the end of Long Wharf, two-thirds of a mile outside of the old coast line and near the deep-water channel of the bay, the hard-pan was reached at a depth of 45 feet below mean-tide level; 13 of the 45 feet being salt water, and 32 mud.

d. In the construction of the new Long Wharf for the Canal Railroad, situated only twenty rods east of the old Long Wharf, and extending to the same deep-water channel of the bay, the piles, at the extremity, and for the greater part of its length, as I learn from Mr. Yeamans, the Vice-President, were driven down 43 to 45 feet below mean-tide level, the longest being those between its middle and the land. In driving other piles over the old Canal basin (which adjoins the wharf on the north) it was found that a region of very deep mud extended eastward not far outside of the present line of yards and buildings, which was evidently the former submarine bed of the old *East Creek* channel (whose waters, it will be remembered, had their discharge into this Canal basin at its head, just east of the old Long Wharf, and close by the commencement of the new wharf). In the eastern corner of this basin, after crossing this mud-channel, a hard impenetrable bottom was found at 18 to 20 fathoms.

e. In driving piles for the bridge of the New York Railroad, across West River, toward its mouth, the hard-pan was found at a depth of 35 to 40 feet; and for the Derby Railroad crossing, a little farther north, at 25 to 30 feet; in one case 40 feet. In these, and other cases, the layer was not so thick but that the piles could be driven through it, and when thus passed, they descended many yards before finding good bottom again. Farther south in West River, at the Kimberly avenue crossing, hard bottom for piles was found (in 1848) below 42 feet of mud.

f. The piles for the Air-line Railroad, over the Quinnipiac meadows, found a hard bottom at a maximum depth of 40 feet.

g. In 1869 piles were driven in the *West Creek* region, near the southeast corner of Congress avenue and Oak street, which descended 20 feet before striking a hard bottom.

h. An artesian well sunk by the Messrs. Trowbridge on Long Wharf, about 350 yards outside of the old coast line, found a supply of fresh water, but slightly brackish, in a layer of gravelly hard-pan, at a depth of 20 feet, or 14 feet below mean-tide level.

i. Another artesian well on the same wharf, but 400 yards farther from the old coast line, made by Mr. Aaron Kilburn under the direction of Capt. S. J. Clark, found water at a depth of 56 feet. The boring (6 inches in diameter) passed through 28 feet of mud; and then about the same thickness of earth resembling the ordinary sand beds of the plain, without any large stones; and the water at first rose to a height of 6 feet above the top of the wharf. Allowing for the height of the wharf, and the penetration of the hard-pan to a depth of 3 feet, the layer here lies 45 to 48 feet below mean-tide level. The depth consequently was very nearly the same with that ascertained by pile-driving at the end of the wharf.

j. At the Staples Block Factory, on Long Wharf, just north of the Messrs. Trowbridge, an artesian well was sunk by Mr. Kilburn to a depth of 45 feet below the surface of the wharf, or 39 feet below mean-tide level, and perfectly good fresh water obtained. The boring passed through 32 feet to the bottom of the mud, then through sand and gravel like that of the New Haven plain, in the course of which there were 2 feet of hard blue clay, a very hard hard-pan, as Mr. Kilburn describes it.

k. On Long Wharf (as I was informed in 1874 by Brown & Co., plumbers, State street) an artesian well was sunk for the purpose of obtaining fresh water for a brewery; it went down 6 feet in salt water below mean-tide level, then through 13½ feet of mud, 3 feet of gravel, 33 feet of sand, and finally 3 feet of gravel; and at this depth, 58½ feet below mean-tide level, obtained pure, soft, excellent water, the discharge 60 gallons a minute through a two inch pipe. The temperature of the water, according to my informant, was 48° F.

l. In another artesian boring, made by Mr. Kilburn, at the depot of the New York and New Haven railroad, east of the commencement of Long Wharf, good water, entirely free from brackishness, was obtained at a depth of 68 feet, or about 60 feet below mean-tide level. The boring passed through 36 *feet of harbor mud*, and, below this, through *sea-shore* or *worn sand*, which was coarser below. The great depth to water at a point so far inside of the Trowbridge and Staples wells, and also the thickness of the deposit of mud, are accounted for by the fact that the place was just within the mouth of the *East Creek* estuary.

An artesian boring by Mr. Kilburn in Howard, now Audubon, street, opposite McLagon & Stevens's factory, descended through 60 feet of quicksand, and struck the solid sandstone rock at a depth of 68 feet. The sandstone was that of the underground slopes of Sachem's ridge. This 68 feet is full 40 feet below mean-tide.

m. In Greene street, at the India Rubber Works, about 50 rods above the Gas Works, an artesian well was sunk, under the direction of Mr. H. Hotchkiss, to a depth of 250 feet. But the existence of a hard layer was not noted, and is uncertain. The material passed through was mainly like that of the plain for 140 feet; a hard layer, a foot thick, was passed at 15 feet below the surface; after going down 140 feet, a bed of "splendid" clay, 14 feet thick; and below this the same essentially as above. At the bottom the tubing was badly bent by striking against something supposed to be rock, and the boring was consequently suspended. It is not known whether the rock was solid sandstone or a loose mass.

1. The facts show that a hard layer, called *hard-pan*, may be reached beneath the harbor, and the estuary part of the Quinnipiac and West Rivers, at depths mostly between 30 and 45 feet; that its depth along the north side of the deep water channel of the bay is 40 to 45 feet; that this continues to be its depth through

nearly two-thirds of the line of the Canal railroad wharf (or much farther northward along this wharf than along Long Wharf, owing to the fact that Long Wharf was built out as the extension of a sandy point between East and West Creeks, while the new wharf is situated off the mouth of East Creek); that toward the shore the depth of the hard-pan generally decreases.

2. That the hard-pan is one of the layers of the stratified drift, that is, of that portion of the drift which was deposited over the bottom of the bay and rivers.

3. That the layer varies in thickness; that it may generally be penetrated by a continued driving of a pile; and when passed, the pile goes easily through a great depth of material before another hard layer is found; and that this soft material beneath the first hard-pan layer, although sometimes described as mud, is probably wet uncompacted sand or gravel.

4. That the hard-pan *may be* in most cases the *same* particular layer of the drift formation; but that we do not know facts enough to authorize the assertion that this is true; or enough to establish satisfactorily its probability.

5. That the hard-pan in some cases is probably a gravelly layer firmly compacted. The region north of the head of the harbor, in the direction of the Canal railroad and the Mill River valley, is underlaid, as has been shown (p. 71) by a very coarse gravel, as the result of the central tidal flow of the bay in connection with the currents of the streams; and it is probable that this gravel-course extends out beneath the harbor; and this may be the hard-pan layer that is reached by the piles. It would naturally have an inclination seaward, following the slope of the bottom of the bay. Along the valley of West River and that of the Quinnipiac, there were doubtless similar gravelly layers formed below, through like means, which may be the hard-pan encountered in the beds of these streams. Yet this is only a suggestion, to be tested by future examination. None of the hard-pan has ever been brought up to the surface, and nothing positive is known as to its nature or the cause of its hardness. It may owe its hard-pan quality to a partial cementing of the material by means of oxide of iron, an ingredient always present in the sand and gravel and the source of the prevailing color, and often causing the waters that flow through them to become strongly chalybeate; besides being a common cement among rock strata. The coarse gravel beneath State street and the Mill River region is in almost all parts very hard digging, owing to its firmness, and for thick beds perhaps nothing more in the way of firmness would be required than what here exists.

II. HEIGHT OF THE LAND IN THE GLACIAL ERA.

With regard to the height of this portion of Connecticut above the sea in the Glacial era we have as yet few facts for a conclusion.

a. In the artesian well on Greene st., 120 yards from the harbor, the bed of clay 14 feet thick, struck at a depth of 140 feet, or 126 feet below mean tide level, was evidently a mud deposit, or, perhaps, "bowlder clay," made in the harbor as it existed immediately before the deposition of the sand; and as the sand beds of the New Haven plain derived their material from the glacier, the condition very probably was that of the Glacial era. If the land then stood 125 feet above the present level, the mud bed would have lain just at the water's surface, like those of the present day. This evidence as to the level of the land in the Glacial era is uncertain; still it affords a presumption that the land was at least 125 feet higher than now relatively to the sea-level.

b. The facts from the bay off the mouth of the East Creek (see § *l*, page 5) show that this stream has a deep under-bay channel; and such a channel as could have been excavated only by fresh waters when the land was at a higher level than now, but the depth of the channel has not been ascertained, so that the amount of elevation required for its excavation is not known. Even half a mile north of the bay, the channel excavated for the stream in the sandstone is 40 feet deep, as above stated (p. 5), below mean-tide. This area of high level was probably that of the old glacier. The Beaver Pond depression affords similar facts, as reported from the survey of Mr. Sylvanus Butler on page 119. The evidence of elevation in these cases is not positive, because the glacier may have excavated in the soft sandstone of the region to depths below the sea-level.

c. Near Stony Creek, eleven miles east of New Haven, on Smith's Island, one of the "Thimbles," there are two pot'holes in the hard gneiss rock; one of them is 7½ feet deep, and 3 in diameter, and the other 3 feet deep and 10 inches across. They are situated within a few yards of one another upon the shores of the small island, but above high tide level. The large one contained, when recently opened by Mr. Frank Smith, its discoverer, many large rounded stones. Another pot hole of less depth exists upon Pot Island, about a mile to the southeast of Smith's Island. It is like a bread-trough in shape, and is 4 and 2 feet in its diameters, and 1½ feet deep. Still another, as I am informed, occurs on Rogers' Island, one of the westernmost of the same group. It is within reach of the tides, and is 4 feet deep and 2 in width. These pot holes must have been made by torrents from the land. Such holes have been attributed to the fall of water from the surface of a glacier; but if a glacier moves even a foot a century such waterfalls would make elliptical holes or elongated trenches, if any, not circular holes like the borings of an auger and ordinary pot-holes. For the existence of such torrents the land should have been above its present level. We cannot fix positively the era of this higher level, but it may have been that of the great glacier, and the torrents, sub-glacier streams then existing.

d. The valleys of the streams of Connecticut, and even those of the north side of Long Island, are in general continued over the bottom of the Sound beneath its waters, apparently excavated for the most part out of the sand and mud deposits which constitute it; and this fact appears to indicate that the Sound was once dry land—a great east-and-west depression of the surface—into which the streams of the adjoining country flowed, and there concentrated their waters in a grand central river which received the existing Connecticut a few miles before entering the Atlantic. The excellent chart of the Sound by the U. S. Coast Survey, which is covered with figures indicating the soundings, enables any one interested in the subject to draw the lines of equal depth, and verify this statement. There is nothing in the depth of the Sound to render the above supposition incredible. An elevation of 100 feet would now lay bare all but a fifth of its bottom across from New Haven, and one of 140 feet the whole breadth; and one of 200, would dry it up all the way to the line of New London, 50 miles east of New Haven. Further, a rise of even 50 feet would wholly separate the narrow western portion of the Sound from the more eastern by a bare area in the meridian of Mamaroneck and Rye, or 50 miles west of New Haven. Only the broader depressions corresponding to the courses of streams are to be looked for over the bottom, even with the fullest possible series of soundings. For like all New England, the Sound received vast deposits of gravel and sand in the Champlain era from the depositions of the great glacier; and ever since these depositions were made, the rivers have been carrying in detritus, each year making its large contributions; the estimate, therefore, that the original surface, as it was before the Glacial era, had been covered by all these deposits to an average depth of 50 feet, cannot be excessive. After such a process tending to obliterate all depressions, especially over the northern half of the Sound which has received the most of the detritus, it is certainly obvious that better defined river channels than exist are not to be expected.

But the conclusion from the existing channels above suggested has at least three sources of doubt—*one* arising from the present action of tidal currents; a *second*, from outflowing under currents which occur at times in connection with large bays; and a *third*, from the configuration of the rocky basement beneath the mud and sand of the bottom of the Sound. * * * *

Yet notwithstanding all the doubts from the above mentioned sources, there are so many examples of depressions leading from the bays at the mouth of rivers over the bottom of the Sound, so many in which the outflowing under-currents of bays appear to be insufficient to account for the facts, either because the bay is not of the shape to produce appreciably such an effect, or there is not in the currents the proper accordance with the ebb in direction, that we think the facts afford strong evidence in favor of a former elevation of the region—an elevation probably not less than 150 feet. In such a case Long Island would have been literally the southern border of New England, and the universal glacier would have had no great basin of salt water to span in order to reach what is now the Island, and depōsit there the bowlders of Connecticut rocks, some of which, as Professor Mather states, (Rep. Geol. N. Y., 4to, 1843) are from 500 to 1000 tons in weight.

It is difficult to explain the facts in detail with regard to the Sound, without a map at hand. The following observations on the subject are however here added.

The main course of deep water through the Sound, west of the meridian of Guilford, commences near the northern shore of the Sound off Coscob harbor and Greenwich Cove (near the boundary between Connecticut and New York), and just here enter Byram, Mianus and Turn rivers. From this region it stretches eastward, passes the north point of the Eaton Neck spit, leaves "Middle Ground" to the north (and consequently in this part is *south* of the middle of the Sound), and then continues directly eastward till it *almost touches the north coast of Long Island* (being less than a mile off) on the meridian of Guilford. At the east *end* of the deep water channel the depth is 18¾ fathoms; and then the depth diminishes abruptly to 11½, 10 and 9 fathoms. This great range of deep water, seventy miles long, that commences in the west near Greenwich, must, as already observed, owe something of its depth, in its eastern portion at least, to its distance from the northern shore of the Sound or the region of rivers and detritus; and, again, it may have had its course determined originally by an east-and-west depression in the configuration of the basement rocks of the Sound. Still it affords some reason for believing that it once contained the channel of a great river. It begins against the north shore near Greenwich, just where three streams enter the Sound, as if a continuation of their united channels. Its depth at its eastern extremity, and its abrupt termination there, are reasons for inferring that it once continued still farther east, and was probably kept open by a flow of water along it. If the land were formerly higher by 150 feet, as has been supposed, the required conditions would have existed for making it a river course. But the query comes up, where in that case would have been the discharge? Its abrupt eastern termination takes place right opposite the large and broad Peconic bay which divides the eastern end of Long Island for a distance of nearly 20 miles (making the Island in form like the profile of an alligator, with its long mouth (Peconic bay) wide open); and the interval of dry land between the Sound and this bay is hardly three miles wide. Moreover, directly in the line of the depression, the land is low, and is intersected by Matituck lake, and also by various channels on the Peconic side. These facts lead to the supposition that this Sound stream of the Glacial era, whose tributaries included the Housatonic and other rivers to the west, may have discharged through an opening into Peconic bay, and that this opening was filled up by sands during the following era of submergence (the Champlain era), and cotemporaneously the southern portion of the Sound farther east was made shallow by the same means.

III. BONES FROM THE CLAY-PITS OF NORTH HAVEN.

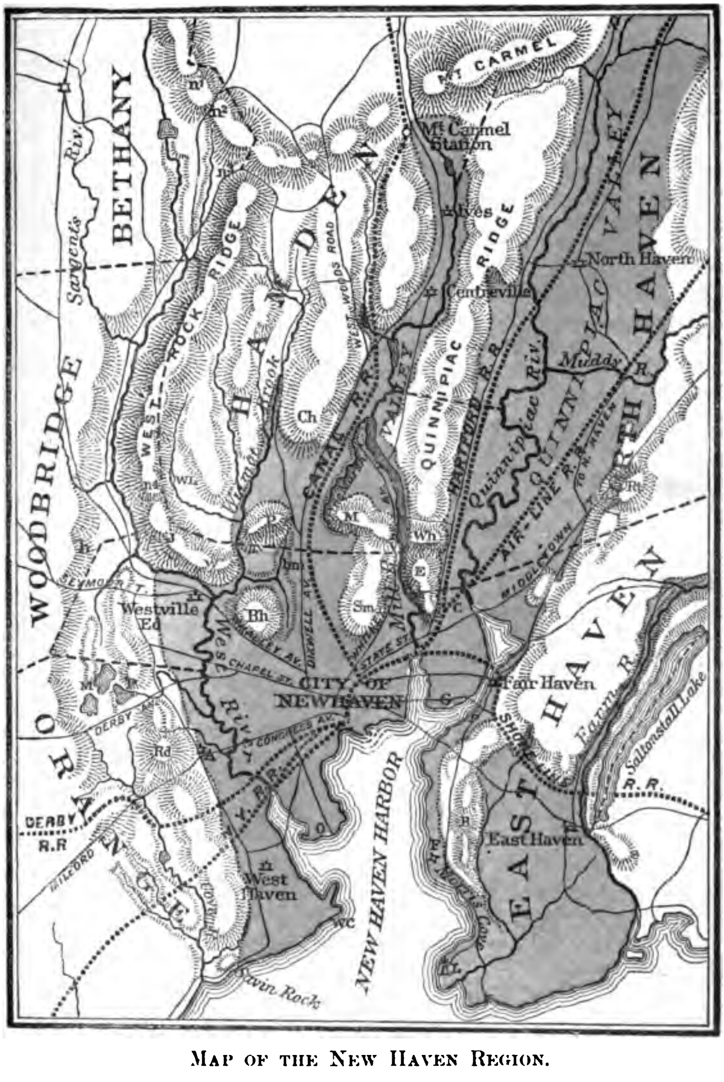
The clay deposits of the Quinnipiac valley, which occur on both sides of the river south of North Haven, and extend beneath the sands to an unascertained distance (probably a mile if not more) north of this village, were probably made, as I have elsewhere explained, during the early part of the era of the glacial flood. The clay is regularly laminated, showing the action of quiet water in its deposition; and as the laminæ, which average half an inch in thickness, consist of a thicker portion of "fatty" clay and another of fine sandy clay, the two alternating, there is evidence that the waters, during the deposition of a layer, varied somewhat in rate of flow, the finer clayey portion being a deposit of the more quiet stage. This alternation may be a consequence of alternation from high to low water, connected with the changing seasons.

More than thirty-five years since, or before 1850, according to Mr. I. Lorenzo Stiles, the antlers of a buck were dug up at a depth of 10 or 15 feet at the Stiles clay-bed, near North Haven village. Mr. Stiles informs us that they were those of the common species of deer. The specimen was deposited in the New Haven Museum, an institution which years since came to its end, and it has been lost sight of, so that the fact with regard to its species cannot be verified. It is also stated by Mr. Stiles that impressions of leaves have been found in the clay.

To the above statement from the writer's "Geology of the New Haven Region" (p. 86), we have to add the discovery by Capt. S. P. Crafts, in his clay-pit at Quinnipiac, of Reindeer bones, as reported by the writer, in the American Journal of Science, vol. x, 353 (1875). The bones are a humerus and a tibia; but, as stated by Professor Marsh, who determined them to be those of the Arctic Reindeer, they were from different individuals, the humerus or bone of the arm belonging to a younger and somewhat larger animal than the tibia. The humerus was taken from a depth of 11 feet in the clay, and the tibia afterwards at a depth of 7 feet. The clay-pit has afforded one bowlder of trap four feet in diameter, and a few others of smaller size. In view of this discovery at Quinnipiac, there is some reason for suspecting that the antlers from the Stiles pit may have been those of a Reindeer.

Such facts appear to show that Arctic Reindeers were then common in Connecticut and other parts of the country along the southern borders of the great glacier. The bones were very perfect, proving that they had not been transported any great distance.

AM. JOUR. SCI., Vol. XXVII, 1884. Plate I.



MAP OF THE NEW HAVEN REGION.

The colored part is the area of the terrace formation. Scale $\frac{4}{10}$ inch = 1 mile.

Explanations.- A, Allingtown. B, Beacon Hill. Bh, Beaver Hills. Ch, Cherry Hill. E, East Rock range, consisting of East Rock to the north, next south Indian Head, and further south Snake Rock. Ed, Edgewood. F, Fort Hale. *F*, Ferry Point, or Red Rock, on the Quinnipiac. G, Chapel Street. J, Judges Cave, on the West Rock ridge. L, Old Light House. M, Mill Rock. M P, Maltby Park. O, Oyster Point. P, Pine Rock. Rd, Round Hill. Rt, Rabbit or Peter's Rock. Sm, Sachem's ridge. T, Turnpike; also Tomlinson's bridge, across the head of New Haven Bay. V, Whitneyville. W, West Rock, the south end of West Rock ridge. W C, West Cape, or West Haven Point. Wh, Whitney Peak. W L, Wintergreen Lake. *b*, 1200 ton bowlder in Woodbridge. *bm*, Beaver Pond Meadows. *n*1, *n*2, *n*3, *n*4, different notches in the West Rock ridge; *n*1, *n*2, the upper and lower Bethany Notches; *n*3, the Hamden Notch: *n*4, the Wintergreen Notch.